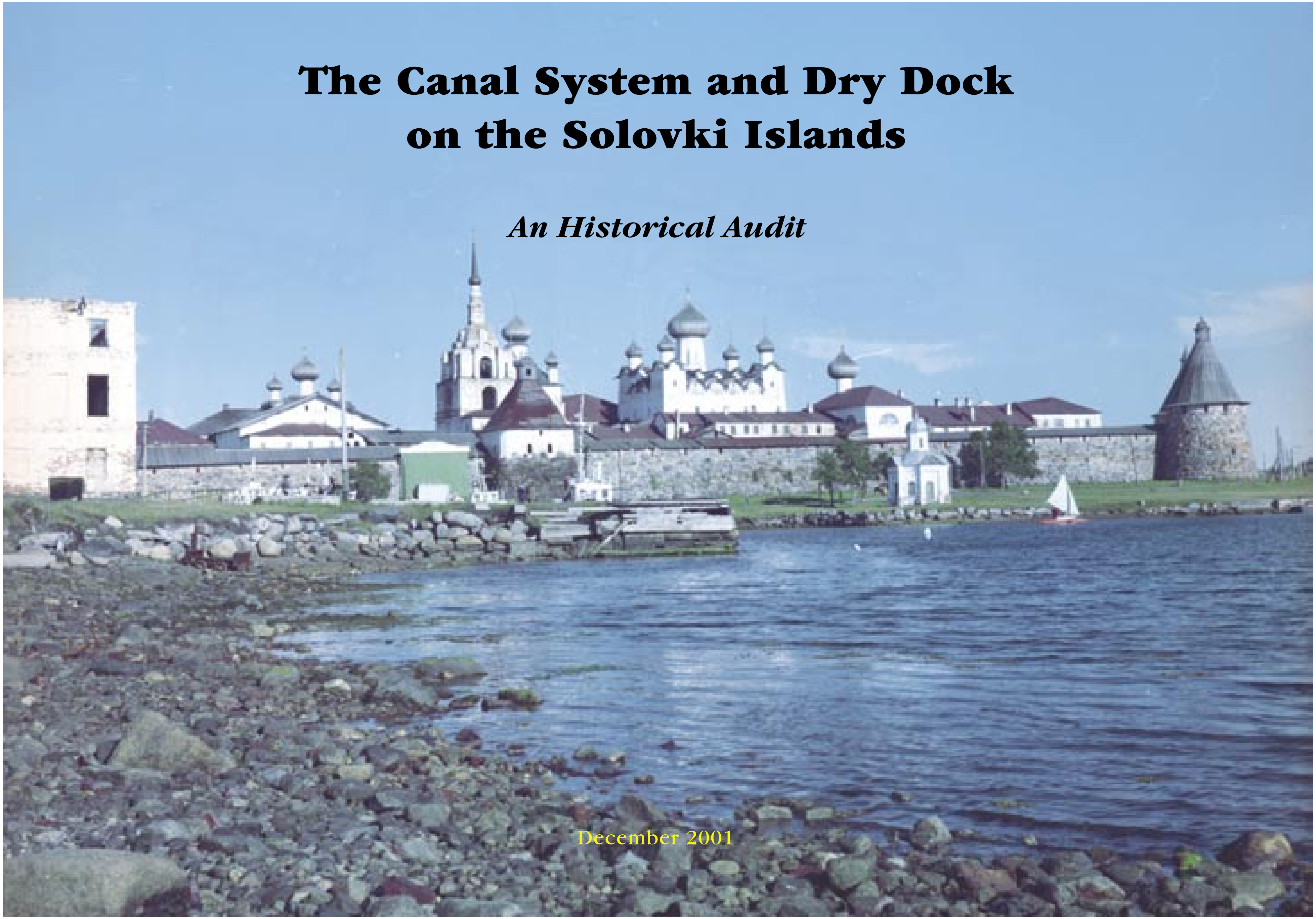
The Canal System and Dry Dock on the Solovki Islands

An Historical Audit



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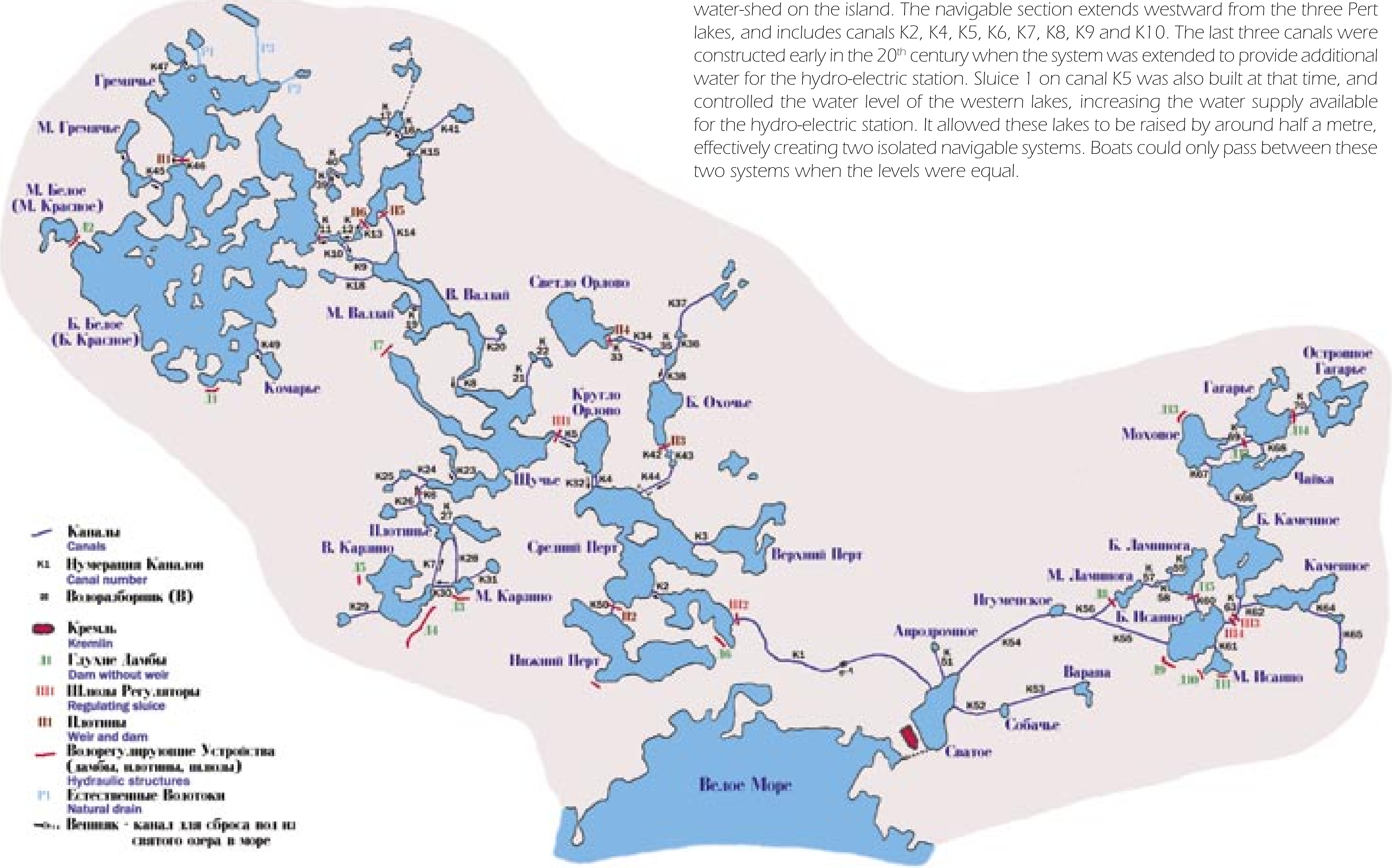
An aerial view of the monastery, with the dry dock and hydro-electric station just outside the walls to the right, and the Saint Lake behind.

The rebuilt southern entrance to canal K8.

Southern entrance to the unrestored canal K5, built in the 16th century and rebuilt in the late 19th century.

THE CANAL SYSTEM

A map of the water supply and canal system which developed around the central water-shed on the island. The navigable section extends westward from the three Pert lakes, and includes canals K2, K4, K5, K6, K7, K8, K9 and K10. The last three canals were constructed early in the 20th century when the system was extended to provide additional water for the hydro-electric station. Sluice 1 on canal K5 was also built at that time, and controlled the water level of the western lakes, increasing the water supply available for the hydro-electric station. It allowed these lakes to be raised by around half a metre, effectively creating two isolated navigable systems. Boats could only pass between these two systems when the levels were equal.



1 Summary

An historical audit of the main navigable canal system on the Solovki Islands was carried out to assess its historical development and importance in local, regional, national and international terms. Historical document sources and reports in the archive of the Solovki Museum were inspected and the system itself was appraised in detail over two days. The report presents a general introduction to the development of water control in general and the system in particular. The various hydraulic structures which form the system are considered, together with the technical aspects of the construction of the canals themselves. A series of recommendations are made as to the possible conservation, operation and interpretation of the system.

Throughout the report, the term canal is used to describe these waterways as it is difficult to define, in simple terms, the difference between a navigable canal and a drainage channel in the circumstances found on the islands. A watershed is both an area of connected drainage channels and the high ground between two such areas.

Canal K4 looking north. The canal is narrower than it appears as the banks have been submerged. Water levels were probably altered when the hydro-electric station opened early in the 20th century.

The original harbour lies to the south of sluice 2 and canal K1. It is now only used by local people, tourists using the boat-hire base further north.

Near the middle of canal K6. The stone bank protection is typical of several of the island's navigable canals.

2 Introduction

The western end of canal K3, one of the water supply canals. The sides of the canal have been protected with stone to prevent erosion. Wood was also used for this purpose.

2.1 Background

The Solovki archipelago comprises six islands situated in the south-west of the White Sea. In total, their area is approximately 300 square kilometres. They have been inhabited since the 5th Century BC, and man-made structures can be found dating from as far back as the 3rd Millennium BC. A Russian Orthodox monastery was established on the archipelago in the 15th Century, and several churches built between the 16th and 19th centuries survive. The monks also developed industry on the islands, and many small-scale industrial buildings can be found. One aspect of this industrial development was the creation of a canal system for agriculture, transport and water supply. Between the 1920s and the 1990s, the islands were used at various times as a concentration camp and military base. The Solovki Islands were declared a World Heritage Site in 1992. More details can be found in Appendix 1.

This audit looks at the history of water control in general, and the main navigable canal system in particular. The problems of conserving and interpreting the system are considered and recommendations made for future action.

The audit was undertaken by Mike Clarke of Milepost Research in co-operation with Dipl-Ing. H-J Uhlemann, the Solovki Museum, Wroclaw Polytechnic and the Russian Institute for the History of Science and Technology.

2.2 Organisation of Report

The report first provides an overview of the development of water control systems in Europe. Then, after describing the historical sources used in the Solovki Museum and providing details of the visits to the navigable canal system, the construction, development and use of the various sections of canal on the island are considered. The history of the navigable canal system is described chronologically, and its development in relation to the hydro-electric plant installed in the early years of the twentieth century is reviewed with suggestions as to how the system was operated. The report closes with a discussion and appraisal of the significance of the navigable canal system, with recommendations for its conservation, operation and interpretation.

As all documents used during research were in Russian, a language of which the author has only a basic knowledge, the report will have some minor inconsistencies, particularly as to the date of construction for some of the smaller canals. However, discussion with staff of the museum and observation of the system itself will have ensured that the information in the report is useful and comprehensive.

3 Water Control and Usage

3.1 General introduction

The provision of a good supply of clean drinking water is perhaps the most basic need for a stable community. It may also be required for agriculture, when this is improved to feed an increasing population. Conversely, drainage may be needed before the land can be used. In either case, the control of water was essential. For those communities near rivers or the sea, floods or high tides could prove devastating, and once again water control technology was needed to protect both community and land. River and tidal waters could also be used for power. Simple water-wheels were used at first, then in the nineteenth century the more efficient water-turbine was introduced.

3.2 Irrigation and drainage

The early civilisations of Egypt, Syria and Mesopotamia, because of climatic conditions, relied upon artificial water supplies and irrigation for centuries. Their techniques were developed by the Romans, who built aqueducts and canals, and refined the earlier Norse or Greek water wheel which had a vertical axle. The more conventional water wheel with a horizontal axle was designed by Roman engineers in the first century, but was only used across their Empire from the third century. One reason for this was that most rivers in the Empire had water levels which fluctuated greatly depending upon the time of year. Mills, generally, were only constructed where river levels were constant or where water was supplied by aqueduct. The Romans also improved river navigation and built canals for both transport and drainage, but following the collapse of the Empire these techniques were lost for centuries.

A Roman irrigation system in the south of France.

The art of land reclamation was slowly rediscovered until, in the sixteenth century, the Dutch Dyke-master Andries Vierlingh wrote his account of the methods then in use in the Low Countries, the first time they were recorded. Land reclamation was often associated with water transport, and the two had been combined in many schemes in the Low Countries from the twelfth century, particularly around the Rhine delta. Locks which could be used by boats were built from 1373, when one was built at Vreeswijk, near Utrecht. Throughout the millenium, Dutch engineers undertook drainage works across Europe, particularly around the Baltic, North Sea, Bay of Biscay and in northern Italy. They were involved with schemes in Russia in the eighteenth and nineteenth centuries. The Dutchman Wollant was Director-General of Transport in Russia at the beginning of the nineteenth century, and he was responsible for, amongst other schemes, the Ladoga Canal and the canal link between Lake Ladoga and the Volga.

3.3 Canals

The development of canal technology took place alongside that of land reclamation and drainage. The problems of using rivers for transport — variation in water depth due to seasonal changes and obstructions such as fishing and mill weirs — also led to the creation of canals. The earliest ones just followed river valleys, the canal running parallel to the river. The first summit level canal, where a watershed was crossed, was the Stecknitz Canal between the Elbe and Lübeck. It opened in 1398, and used flash locks, where a single gate allowed the flow of water to be held back, boats sailing up or down stream on the 'flash' of water released when the gate was opened. This was wasteful of water, and could only be used where there was a good supply. Even then, boats would only pass along the system once or twice a week.

A restored wooden lock in Holland, typical of the many which were used for land reclamation, drainage and navigation.

Chamber locks, with gates fitted at either end of a short chamber large enough for a boat, were first introduced on the canals around Milan, Italy, in the second half of the fifteenth century. Filling and emptying the chamber was carried out by sluices fitted in the gates. The use of chamber locks considerably reduced the waste of water compared to flash locks and led to greater use of canals. The next innovation was on the

The lock staircase at Rogny on the Canal de Briare in France. These locks were built early in the 17th century. They were lengthened in the 18th century and bypassed in the 19th century.

Brussels Canal, constructed around 1550, where sluices for filling and emptying the lock were built into the lock walls. Mitre gates were also used, each end of the chamber having a pair of gates which, when closed, met at an angle. This created a more watertight seal.

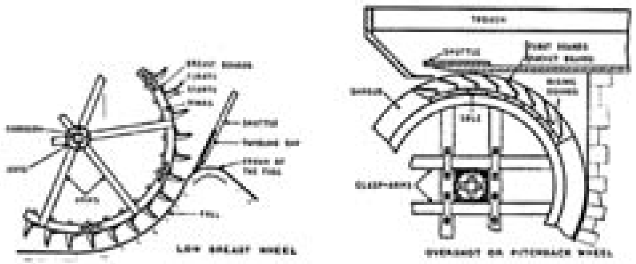
Canal building finally reached maturity in the seventeenth century with the opening of the Canal de Briare (1642) and Canal du Midi (1681) in France. All the structures needed for the design and operation of canals were incorporated in these canals. As well as chamber locks, there were aqueducts, tunnels and reservoirs for water supply, the last being the most important for uninterrupted operation of the canal.

3.4 Water Power

There are two main types of water wheel with a horizontal axle. On the undershot wheel, where water is fed onto the paddles below the axis of the wheel, power is generated by the force of water hitting the paddles. On overshot wheels, where water is fed onto the uppermost part of the wheel and the ends of the paddles are closed, power comes from the weight of water filling the paddles. Both types were probably developed by the Romans, the particular design depending upon location. Undershot wheels needed a large water flow and low fall, while overshot wheels needed a large fall and less water. Water wheels developed over the centuries, but it was not until the mid-eighteenth century that the design was improved scientifically following the experiments of John Smeaton. These resulted in the high breast wheel. Water was fed onto the wheel at about axle level, and power was created by both the force of the flowing water and by its weight. Improved design of the shape of the paddles also ensured better filling by reducing turbulence.

The water turbine was first developed around 1830 by Fourneyron in France. In his design — the reaction turbine — the power shaft was vertical and water was fed outwards from the centre of the turbine. Fixed guides directed the water onto movable vanes which turned the power shaft. The outward flow created problems due to increasing volume which created turbulence, thus reducing efficiency. The inward-flowing turbine was the answer to this problem. Originally designed by Poncelet in 1826, it was improved by Francis, in America, in the 1840s.

The second type of turbine is the impulse turbine, where a jet of water is directed onto vanes or buckets fitted to a wheel. Originally designed by Girard, it was improved by Pelton during the latter part of the nineteenth century. This type of turbine is particularly suitable for large falls of water.



Sections through a low breast or undershot water wheel, and an overshot water wheel. (A pitchback wheel turns backwards)

Hydro-electric generator built by Brown Bovari in the late 1930s for the Eder dam in Germany.

Thomson, in Scotland, developed a reaction turbine within a large spiral casing in 1852, which incorporated pivoting guide vanes. Subsequently the vanes on the power shaft were curved so that the direction of the water became parallel to the shaft. This created a mixed-flow turbine with characteristics of both the impulse and reaction turbine. The result was a compact turbine capable a dealing with large volumes of water.

4 Methodology and Sources

4.1 The range of evidence

This report has been written following a two-week visit to the Solovki Islands at the end of July, 2001. Archive and bibliographic sources within the Solovki Museum were consulted, and the various structures on the canal system visited.

In the Archive were excellent reports by Russian archaeologists undertaken over the last fifteen years. Detailed hydrological surveys of the lakes and canals have been undertaken, giving much detail about water supply and flows through the various canals. The canals themselves have been recorded in detail and a series of excellent drawings and reports produced. There are contemporary documents, but from footnotes in the reports held in the Solovki archive, most of these seem to be in archives in Moscow and St. Petersburg so were not available for inspection. Many sources were probably destroyed in the 1920s when the monastery was severely damaged by fire.

This report is also based on a tour of the navigable canal system. The whole of the system was visited, as well as the water supply canals K3, K12, K13 and K14. Dams D1, D2 and D6 were also inspected as well as weirs 5 and 6 and control sluices 1 and 2.

The lower end of water supply canal K14. This section is formed from a natural valley and is unlined. See pages 16 and 17 for more details of the construction of this canal.

Unrestored canal K10, built in the early 20th century, looking north. There are several types of wooden bank protection to be found on the navigable canals. Some have continuous vertical or horizontal planking whilst others use a wooden framework for stabilising random stonework.

5 The History of Canals on the Solovki Islands

5.1 The Monastery and Water Usage

Monks first came to live on the islands in the fifteenth century, and construction of the monastery started in the following century. It was to continue until the start of the twentieth century, only ceasing when Communism took control in Russia.

To provide a good standard of life so close to the Arctic Circle required the monks to be innovative and to work with their environment. The canal system is possibly the most important aspect of this, as water is vital to the development of culture. The monks were to prove themselves masters of its control and usage.

The canal system was first used primarily for drinking water and for agriculture purposes. Water supplied for power began with the construction of the first mill within the monastery. The earliest canals were probably too small for navigation, but boats and rafts could have been used on the lakes. This function may have increased during the nineteenth century, and steam boats were in use by the early twentieth century. The canals linking the main lakes were enlarged to accommodate this traffic, and as a result of the construction of the hydro-electric power station.

5.2 Development of the System

The island is divided into numerous individual water-sheds, each associated with their own lake system. Some drain into the sea which others are self-contained. The most important areas are indicated on the map, the main canal system being associated with the water-shed draining into the Saint Lake. Over the centuries, this water-shed was extended by the construction of canals and dams. These allowed some water from other water-sheds to be diverted into the main system and thus enhancing the supply to the monastery.

The original system joined Lake Valdai in the north and Lake Karzino in the west to Pike Lake and then with Saint Lake and the monastery through a canal from the Drinking Lake (Lake Daniel) where a sluice controlled the supply. The Upper, Middle and Lower Pert Lakes were the central part of the system, the level of the Lower Pert Lake being raised by dams. Stone for building may have been carried by water from the Lake Karzino area from this time.

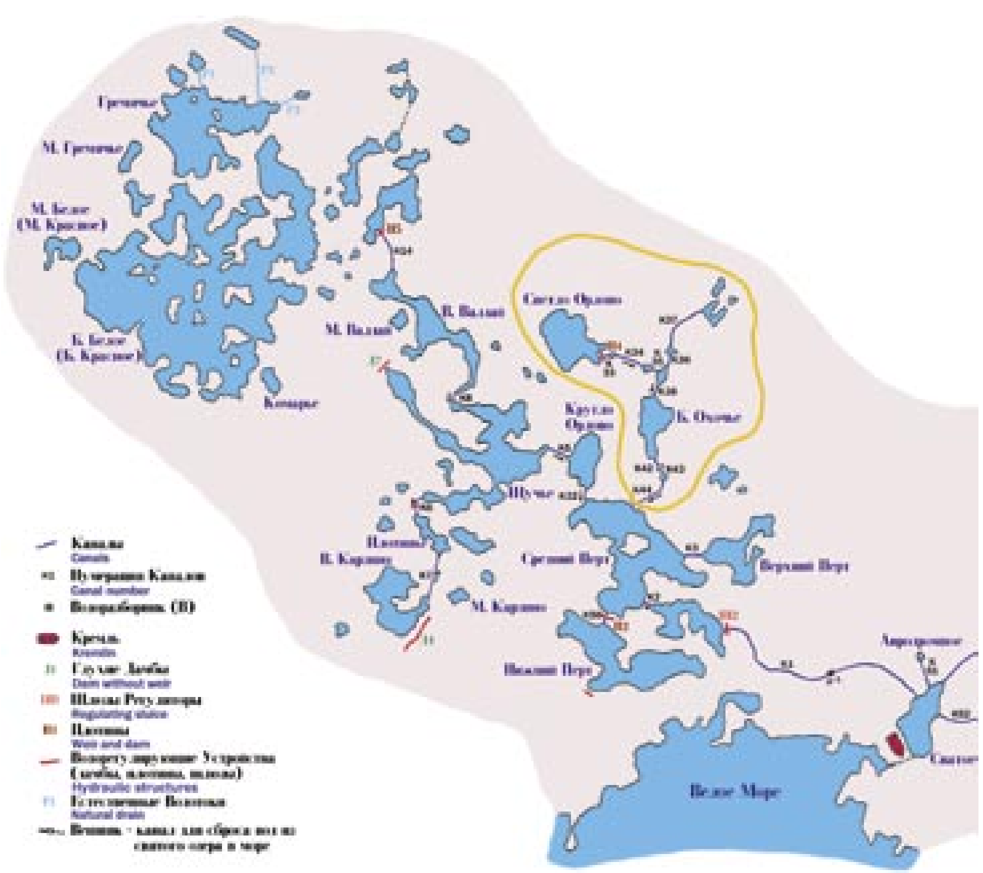
The first extension took place in the eighteenth century when the water-shed of the Clear Orlov and Ohochie Lakes were connected to the system. Previously they had drained eastwards into the Long Bay, but by raising their levels with weirs 3 and 4 their waters could be led westwards to supply the monastery.

The system was further enlarged in the nineteenth century. Two factors probably influenced this expansion; the construction of the dry dock (1799-1801) and the hydro-electric station (1908). The development of the corn mill within the monastery may also have affected the water supply. At first, Lake Zaborno and its associated lakes were connected to the system with weirs raising the level of two lakes so that water could be diverted from its original route into the Long Bay. These developments may have taken place during the first half of the nineteenth century. The increase in water supply created may have been too great for canal K14, and this was eventually bypassed by the construction of canals K12 and K13, though these were built during the next phase of expansion.

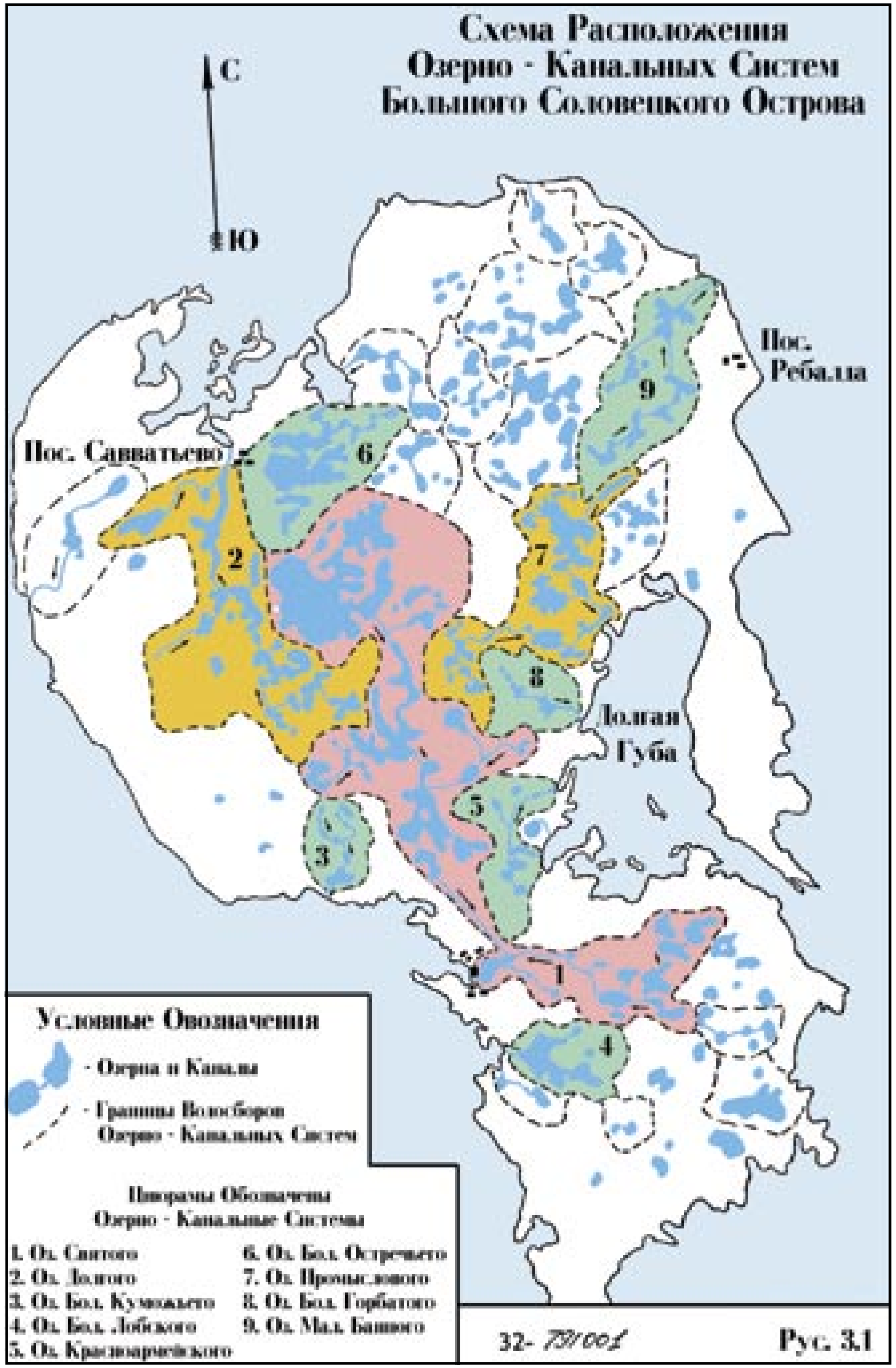
Around 1900, a hydro-electric scheme was proposed to supply the monastery with electricity. This was built between the Saint Lake and the White Sea on the south side of the monastery. The turbine used for power required a much greater supply of water than was available, so the canal system was further enlarged. At the same time, the width of the canals was increased so that small steam-powered boats could be used for transport. This development can be seen in particular on the link between the Circular Lake and the Middle Pert Lake, where canal K4 replaced the much smaller canal K32.

To provide the increased water supply for the hydro-electric scheme, the system was expanded in two areas. The most important was the White Lake (Red Lake) area which had formerly been part of the water-shed draining into the White Sea through Pine Bay. Dams were built to raise the levels in the White (Red) Lakes and in the Thunder Lakes so that they were on a similar level to that of Lake Valdai. However, a ridge of high ground separated the two systems and the new canal joining them required extensive excavation work. In places, rock had to be cut through to a depth of around 10 metres. The level of water in Sheep Lake was also lowered by eight metres so that it could form part of the

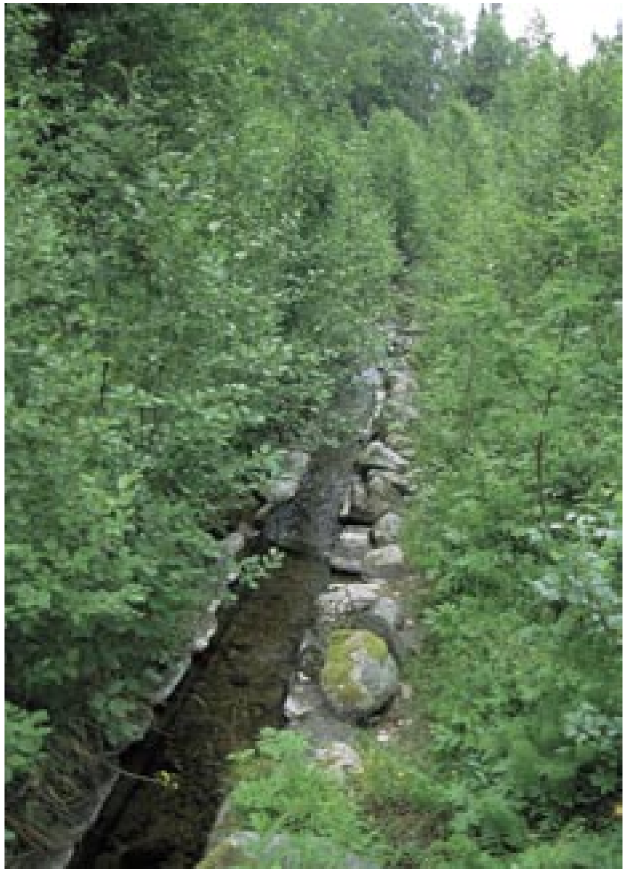
The eastern end of canal K3, one of the 16th century water supply canals. Logs have been used to protect the sides from erosion.



A section of the map on page 3 altered to show the system in the 16th century. The area circled in orange was added in the 18th century. Canal K7 may have been unnavigable at this time, the lakes it serves being added to the system around 1900 at the same time as the waters of the western lakes were also added to the system.



Right: The watersheds on the main island. Area No.1 is the main canal and water supply system, the navigable part being to the north of canal K1. The large lakes to the north of this system were originally connected to area No.6 and drained to the north. During the construction of the hydro-electric station in the early 20th century, this area was connected to area No.1 by new canals to increase the water supply to the new power station. Part of area No.3 was also taken into area No.1 at this time, and several dams were built to raise the water levels.



Canal K1, the main water supply to the Saint Lake.

The eastern end of canal K7, one of those constructed to increase the water supply for the hydro-electric station early in the 20th century. This site has already been developed as a landing stage and camping area for visits to the forests.

Dam D1 was constructed to raise the water level in the lakes now forming the northern section of area No.1. Together with the construction of canals K9 & 10, this allowed the waters of these northern lakes to be diverted southwards and to improve the supply for the new hydro-electric station.

new canal system. Extensive wharves for loading timber and stone were also developed in this area.

The second area to be extended was that around Lake Karzino, where dams D3 and D4 were raised in height, and the water supply improved by building canals to several smaller lakes around this part of the system. Most had probably previously drained westwards to the White Sea.

These extensions of the system were still being completed at the time of the Communist takeover. Work on them ceased, and the full potential of the water supply system was probably never realised. Maintenance was also reduced, and many of the smaller fed canals would have stopped supplying the system as they became blocked. The systems original function — a drinking water supply — remained intact, but the developments associated with the hydro-electric scheme, particularly the new sluice mechanism on canal K5 at the exit to Pike Lake, fell into disuse.

Over the last ten years or so, several of the canals have been restored by voluntary workers, and the whole of the navigable system can be used by small boats. A boat-hire base has been established on Middle Lake Pert and two wooden piers erected for use by boaters to the north and west of the system.

6 Technical Description

6.1 The System Inspected

The canals can divided into two types, depending on whether they were used simply for water movement or for transport as well. The former are usually up to half a metre in width, while the latter are over one and a half metres wide. The canals inspected in detail were the navigable system K2, K4, K5, K6, K7, K8, K9, K10 and K11, and water supply canals K3, K12, K13, K14 and K32. In all the cases inspected, the dams seem to have been of earth with stonework protecting weirs and sluices. In one case, there was stonework strengthening the rear face of the dam.

6.2 Water supply canals

These can be sub-divided into those which have been developed from natural water courses and follow the original surface contours, and those which have required excavation work to allow water from one water-shed to feed into another.

Where the natural contours are followed, the canal is often unlined today. However, some sections have been lined with stone, particularly where there may be excessive erosion, such as at dams or bends. Some excavation work has been carried out in building this type of canal, but it is usually limited in extent. Excavation has a maximum depth of one metre, and is merely used to bypass natural obstructions such as a bends. These excavations are also at the bottom of natural valleys, where slippage of earth into the canal is less likely to be a problem. As originally built, there would almost certainly have been more lining and bank protection on these waterways, probably using wood. Regular maintenance would have ensured that any failure of the lining was replaced and that the waterway was kept clear. However, during the twentieth century, maintenance has not been undertaken systematically, and natural erosion has removed the majority of lining along these waterways.

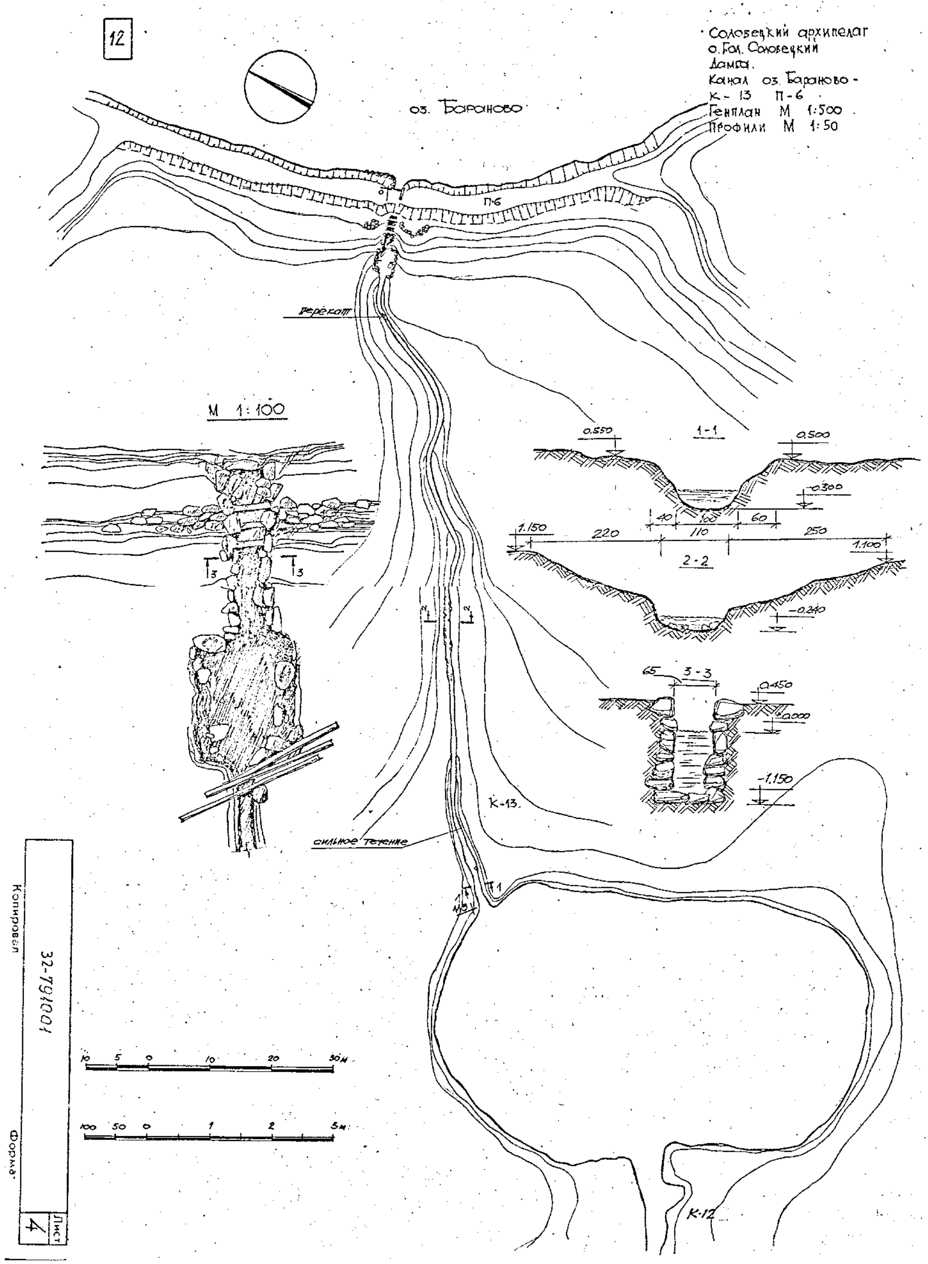
Where the canal has required extensive excavation work, the banks have been protected with wood or stone for most of their whole length. To create the

The house for sluice 2 which controls water supply to canal K1 and the Saint Lake.

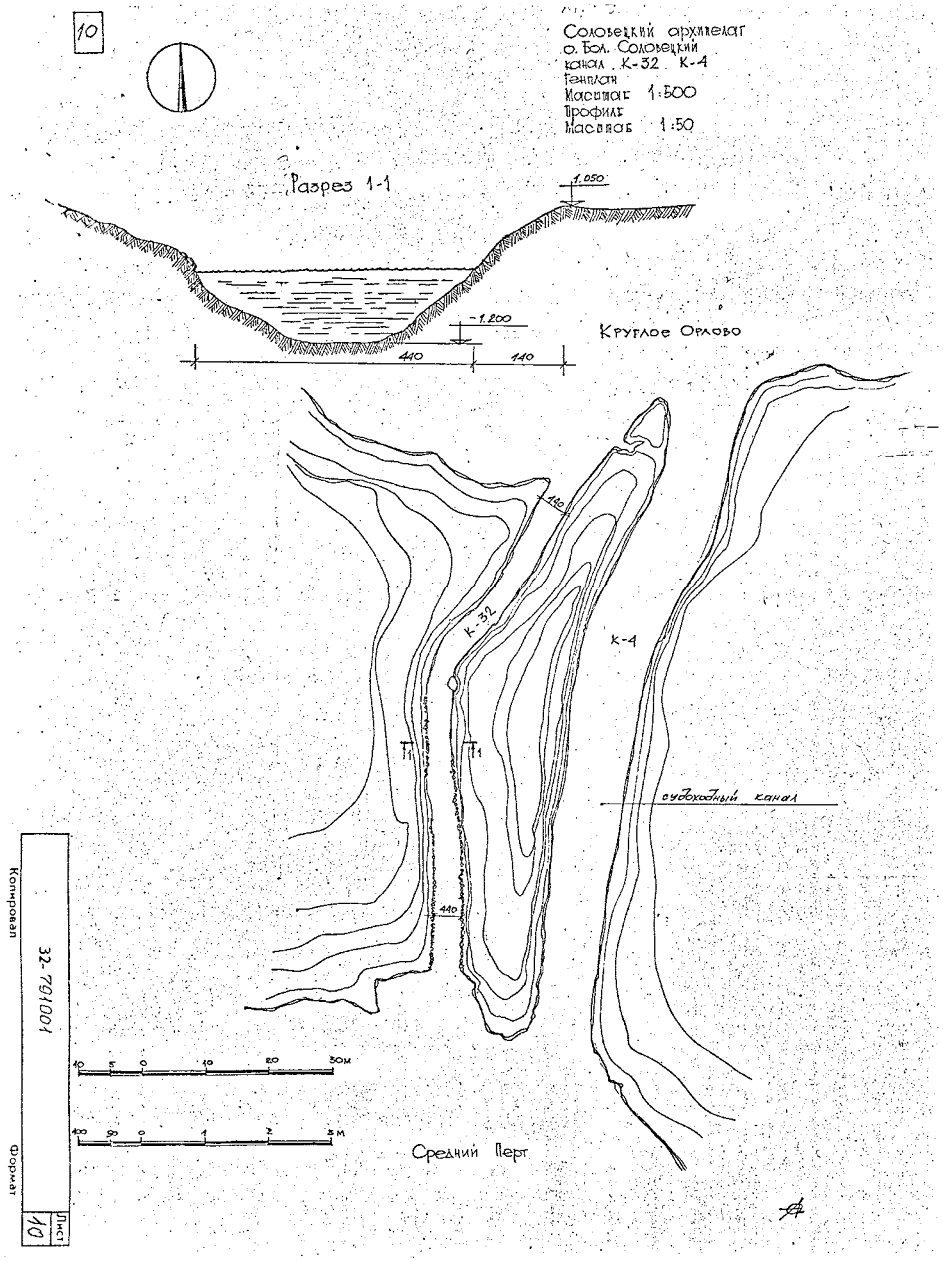
The mechanism of sluice 2.

The entrance to canal K32. This canal was abandoned when the wider canal K4 was built next to it to create a navigable system, as shown in the plan on the far right.

Drawings from the archive in the Solovki Museum.



Plan of drainage canal K12 which replaced drainage canal K14.



Plan of the water supply canal K32 and navigable canal K4 which replaced it.

canals, natural valleys have often been deepened, and at the bottom the canal has been excavated. In places on canal K14, the canal excavation is over two metres deep. It is vital for such excavations to be supported. Either horizontal wooden logs or planks are kept in place by vertical wooden piles, or vertical piling is held together by horizontal baulks of timber. In places the piles are supported at their upper ends so that the excavation cannot collapse inwards. The base of the canal is also lined with either stone or timber to prevent erosion.

6.3 Transport canals

All the canals used for transport are lined with either stone or wood. In some places little survives of the wooden bank protection, but there is enough to confirm its original use. Several sections have been rebuilt. In general, the width of the navigable canals is around two metres, and this would probably have been the minimum required for the steam vessels used on the system around 1900.

On canal K4 the top of the stonework forming the bank protection is underwater, while on canal K5 is only just above water level. This suggests that the water level has been raised and is discussed in the next section related to the hydro-electric station. Canals K6 and K7 have had some restoration work carried out, with work to the stone banks generally and new wooden bank protection at the western end of canal K7. Both these canals are shallow, again suggesting some variation in water levels. Canals K8, K9 & K10 all have banks which extend well above the water level, though those on K9 are unrestored. Here the wooden piling has partially decayed, and in parts there is water behind the piling which suggests that it may have been unfinished.

One feature of the navigable system is the variation in width and depth of the canals. This may be a result of different usage of each section. The narrower canals, K6 and K7, may have been used more for rafting timber, with the wider canals used more by boats. However, the cross-sectional dimensions of the canals may have been reduced during reconstruction.

6.4 Developments for the Hydro-Electric Station

The operation of the hydro-electric station early in the twentieth century would have required large volumes of water, and water storage was increased by the construction of canals K9 and K10 and the addition of the White (Red) Lake system to the water supply. Considerable works were required for this, with more excavation being undertaken to construct the two canals here than on any of the others. Sluice 1 was also constructed on canal K5, enabling the water level of the whole of the western part of the system to be raised, thereby increasing water storage.

When Sluice 1 was closed and the water level raised, boats would not be able to pass between the parts of the system on either side of the sluice. This suggests that the system had a seasonal pattern to its usage. In the Spring the sluice would be closed, and the water from melting snow would be held back for use during the dry Summer period. Towards the end of Summer the level of the two parts of the system would be equalised and the sluice opened. Boats and rafts of timber could then pass through, moving the stone and wood which had been collected during the earlier Summer months. The sluice may have been left open during the Winter, but this would depend upon how severely the canals were affected by ice, and if they became completely blocked.

Although boats could no travel over the whole system when the Sluice was closed, they could still operate on one section. The construction of the canals on the western part of the system, which had bank protection higher than those canals in the east, suggests that there were boats operating on this part when water levels were raised. As boats were probably kept out of water at the eastern end of the system over Winter, this suggests that the Sluice was only closed after the ice had melted and the boats required in the west during the Summer had been moved there.

6.5 Maintenance and operation

The severe winters encountered on the islands would demand that the canal system was inspected every Spring. Any frost damage would have been repaired to ensure that water could continue to flow freely. The lack of maintenance during the twentieth century has resulted in many of the water supply canals becoming blocked or their flow being restricted. Some of the navigable canals have been rebuilt recently, though this may have resulted in their cross-sectional dimensions being reduced.

Sluice 1, above, was built to control the water supply for the hydro-electric station. The gate and gate-raising mechanism have been removed.

7 Discussion and Appraisal

The monastery may have had contact with Italian engineers in the sixteenth century, and Dutch engineers did work elsewhere in Russia in the following century. However, until the end of the nineteenth century, the islands remained somewhat isolated from the influence of modern technology. Consequently the engineering used for constructing the canals is simple and, to those used to the developments elsewhere in Europe during the eighteenth and nineteenth century, somewhat antiquated. The materials used were those which could be found close to hand, and this fits in with the other activities of the monastery where they worked with the environment rather than against it. Today, the canal system still portrays engineering methods which are difficult to find elsewhere in Europe. Only on the developments for the hydro-electric station can more modern techniques be seen.

The whole system, both water supply and navigable canals, provide an interesting example of the development of hydraulic engineering over the last four hundred years. Although there are no major structures, such as locks or aqueducts, the supply and control of water is well illustrated, and this is the main function of any canal system. Water is also vital to the development of society, and the island community's development can be mirrored in the waters of the canal system

Canal K10 was built around 1900. The excavation work was around eight metres deep and its sides are terraced to make them stronger.

Canal K8 has been rebuilt, though the swing bridge crossing it still requires restoration.

8 Recommendations

8.1 Conservation of the Water-Supply Canal System

The conservation and restoration of such a large canal system will be expensive. However, without conservation the system will slowly disappear, as the condition of some of the smaller water supply canals shows. As it is unlikely that in the future the water supply canals will be used in full for their previous purposes, it is suggested that detailed conservation plans are only drawn up for a small number of these. Those which exhibit typical features or which are suitable for public access would be the best ones to be chosen. However, a long-term plan could also be produced where each canal is considered and a scheme for use, conservation or restoration set out. Considerations regarding the water supply to the island community would probably have to be taken into account when considering the importance of each canal.

One group which would be suitable for conservation are canals K12, K13 and K14, and proposals for their interpretation are described below (8.3). This group comprises canals of the two main types — those requiring considerable constructional work and those using existing contours — and there are also two dams and weirs here. It is a compact group, so that conservation work could be concentrated in a small area. Good access would need to be created, and the wood and stone bank protection restored along the three canals. The dams and their water control weirs and sluices should also be restored so that water can be fed down into the main system. A programme of routine maintenance should be drawn up to ensure that any damage by winter conditions is repaired.

8.2 Conservation of the Navigable Canal System

There should be a standard set for the depth and width of navigable canals which will define the size of boats which can use them. There are great variations in the dimensions of the various canals, and some research should be undertaken into their original size. On some canals, lack of maintenance may have resulted in a reduction in cross-section, and the recent restoration programmes may also have resulted in a reduction. In view of the possibility of introducing an electric passenger-carrying boat, it may be worth considering the maximum size of boat which is suitable, and then drawing up a set of standard dimensions for the canals afterwards. However, only minor increases should be made to existing dimensions. Canals K6 and K7 are the smallest, and they may form the limiting factor in deciding the size of boat which can use the system.

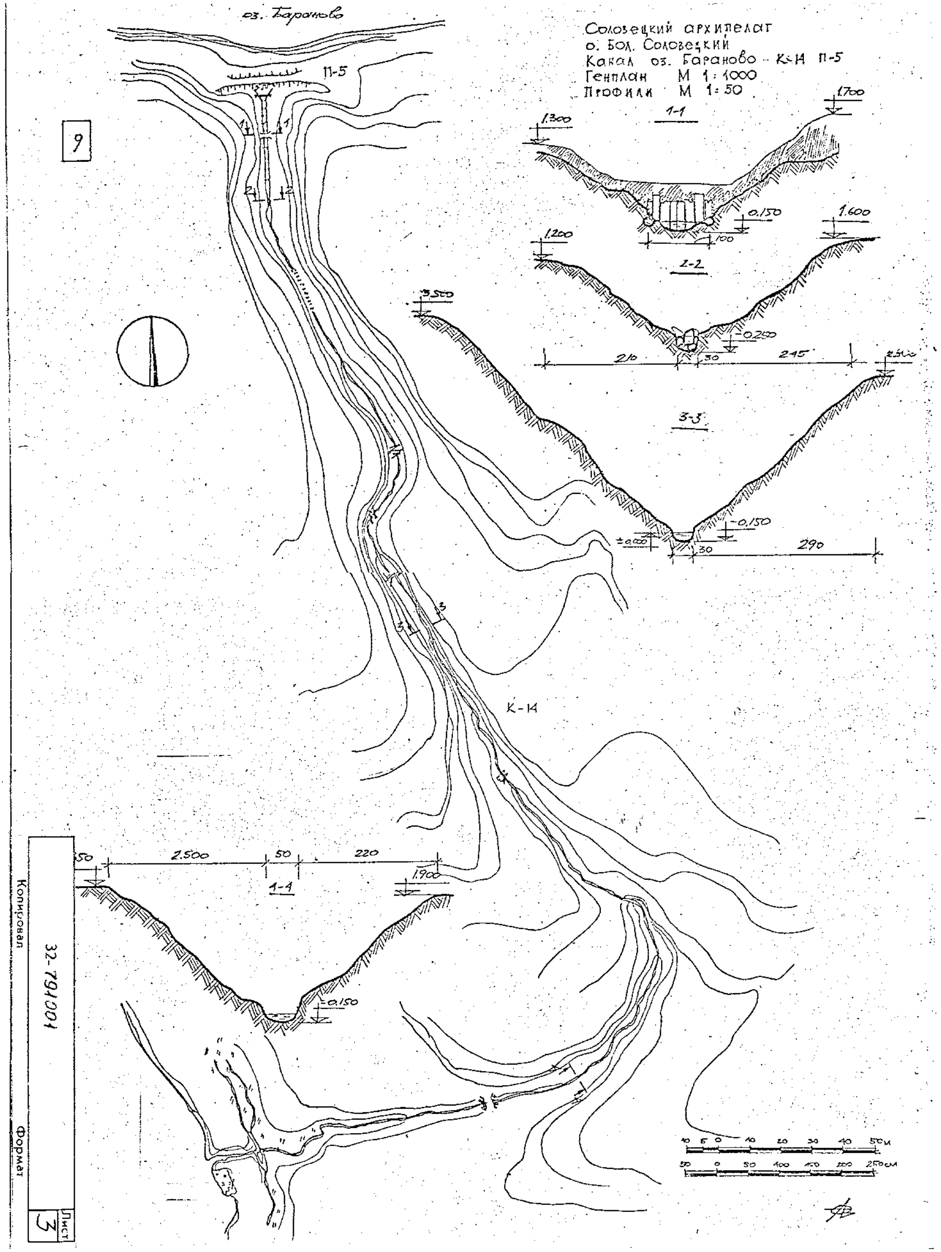
Further research could be undertaken into the various harbours around the canal system, and into their usage. Those most important in relation to the interpretation of the canal system could then be identified, and their conservation and restoration prioritised. Those on Lake Karzino and the White (Red) Lake are particularly important with regard to tourism as they are adjacent to roads, and could be developed in association with other sites on a tourist route. A boat trip could then form part of a tour to other parts of the island. The harbours are also excellent sites for interpretation of the canal system and the areas around it.

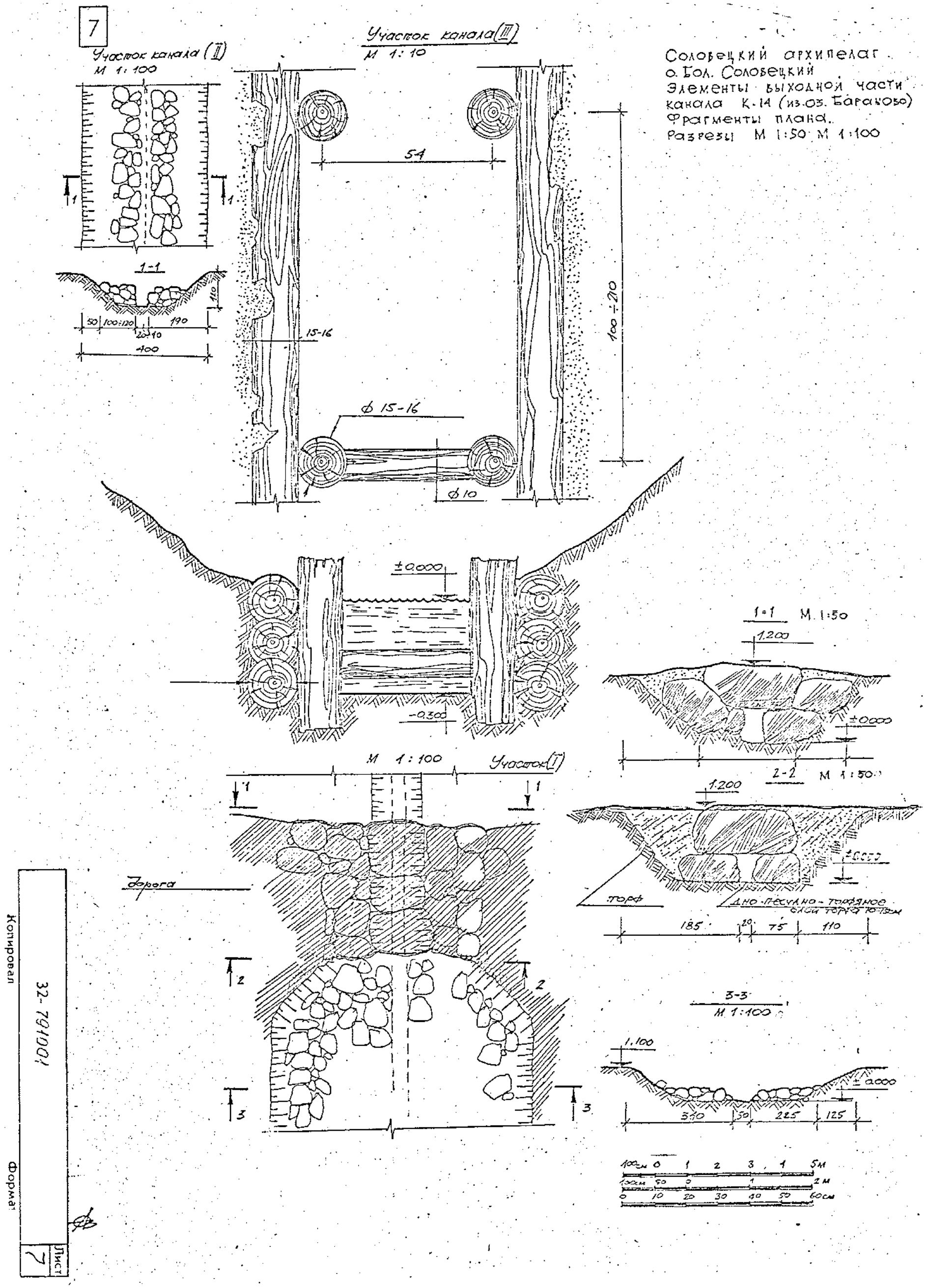
8.3 The Canal System's Interpretation

Besides local interpretation panels at the various harbours, one site should look at the canal system as a whole. The site suggested for this is in the area of canals K9 and K10. A harbour could be developed here around the original wooden structures, and interpretation panels erected showing the construction and extent of the system. A footpath could then be created following canals K12, K13 and K14 , creating a circular route through the forest. The various types of canal can be seen here, as well as two dams and lakes. Together with canals K9 and K10, they form an excellent group which display all the features of canal engineering on the island. These include not just water supply and the construction of small canals, but also the large-scale

Two photographs showing the construction of canal

Drawings from the archive in the Solovki Museum.





Plan and details of water-supply canal K14.

works associated with the extension of the system to serve the hydro-electric station.

Other features which need conservation or restoration to help the visitor to interpret the system are the sluice on canal K5 and the swing bridge on canal K8. Further research should also be undertaken into the condition of the canal banks before the First World War. In particular, the effects of forestry on the canal environment would be of interest to the visitor. How was timber rafted around the system, and how were the trees managed? The swing bridge suggests that there were various footpaths through the forest, and it would be useful to know where these met the canal. Walks in the forest could then be developed around these, perhaps with visitors being dropped by boat at one place and met at a second place further along.

8.4 Documentary Evidence

The Museum's Archive holds much useful archaeological material regarding the canal system, but some still remains in Archangel. Every effort should be made to consolidating the collection so that it can be made available to researchers, and to help in further understanding the canal system. The availability of

Part of the restored section of canal K7. This end of the canal has wooden bank protection, while random stonework is used at the other end.

material in other archives, particularly in Moscow and St. Petersburg, should also be assessed and important items microfilmed so that they are available in the archive on Solovki.

8.5 Publications

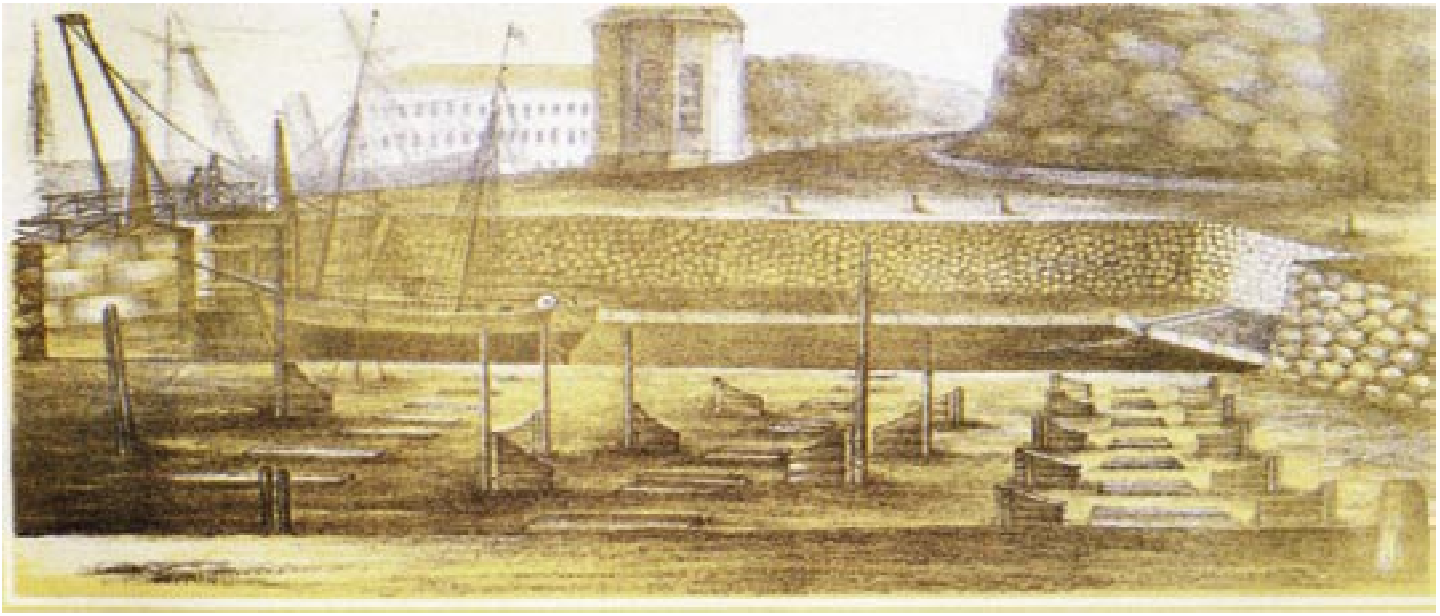
The provision of interpretation boards at locations around the canal system may prove difficult, particularly in view of the severe winter weather conditions. In their place, it would be possible to produce a leaflet outlining the history and development of the canal system and its importance to the island's community. This would include details of the various aspects of the system — water supply, drainage, power and transport — and a description of the technology used. A guide to the system, with information about the most important sites would also be needed. The inclusion of a map would make such a guide of great use to those travelling by boat along the system.

The small size of canal K6 can be seen from this photograph. Improved management of the banks could ensure a standardised navigable width and thus allow electrically-powered boats to use the system.

The old wharf between canals K9 & 10 could be developed as an interpretation site for the canal system.

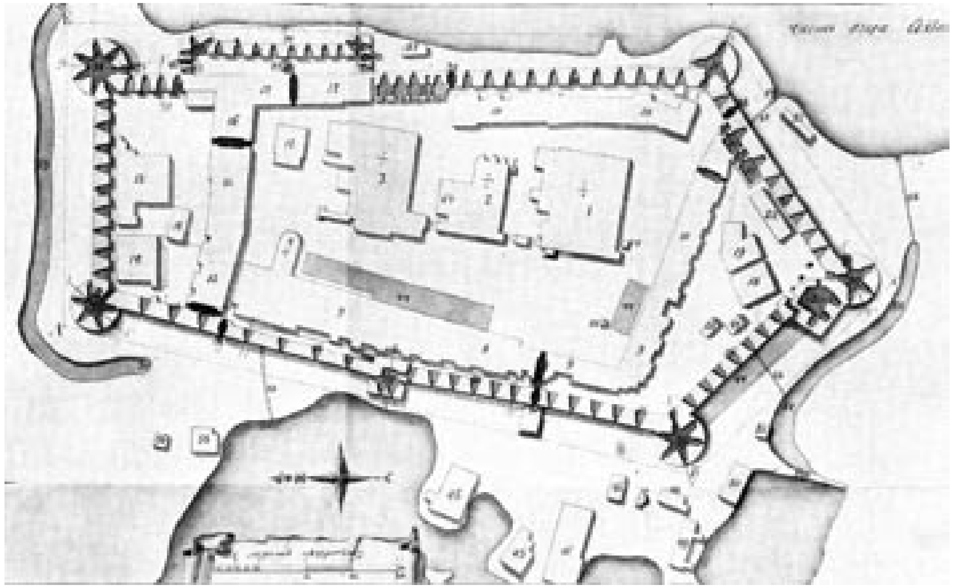
A panorama of the dry dock compiled from photographs taken in 2001.

The Dry Dock

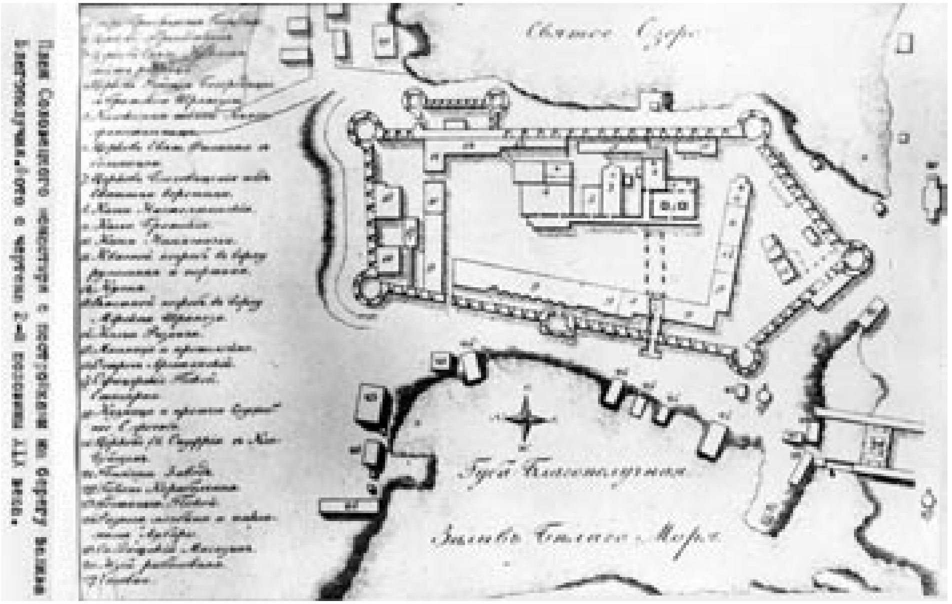


The dry dock from a lithograph of 1884.

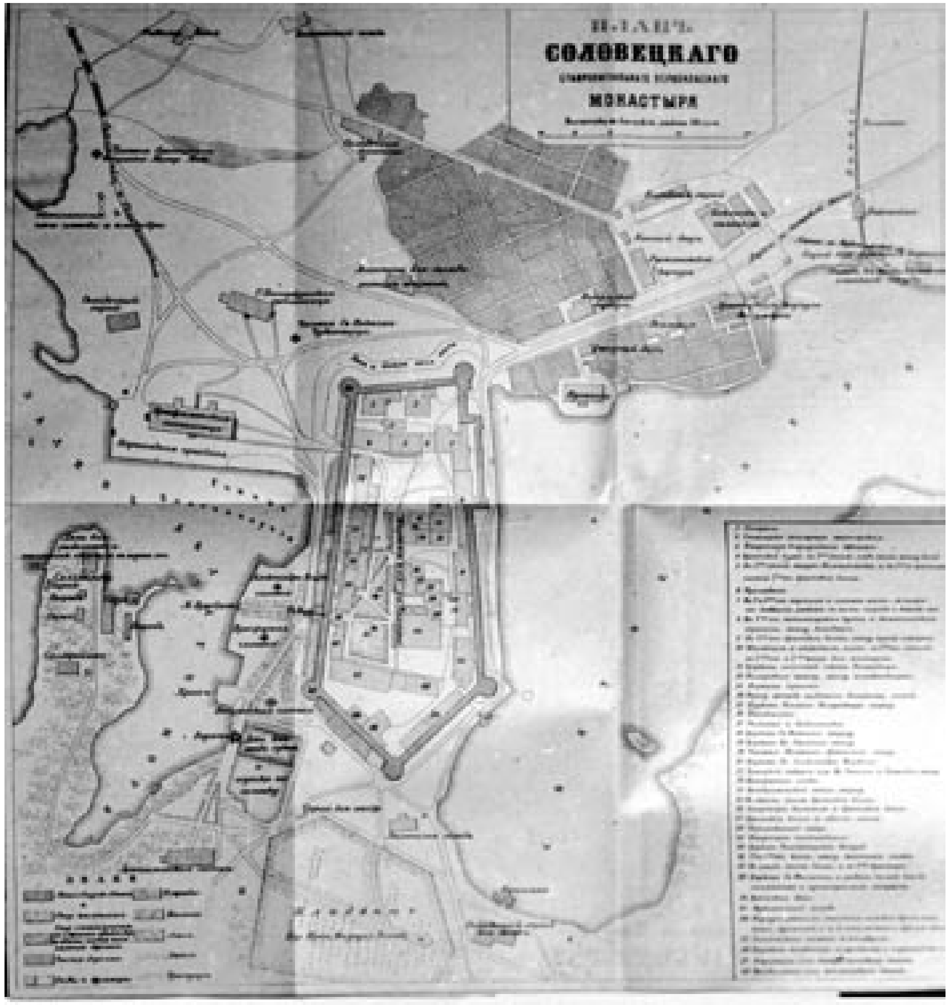
2. Maps showing the development of the Dry Dock



The monastery circa 1790, before the dry dock was built.



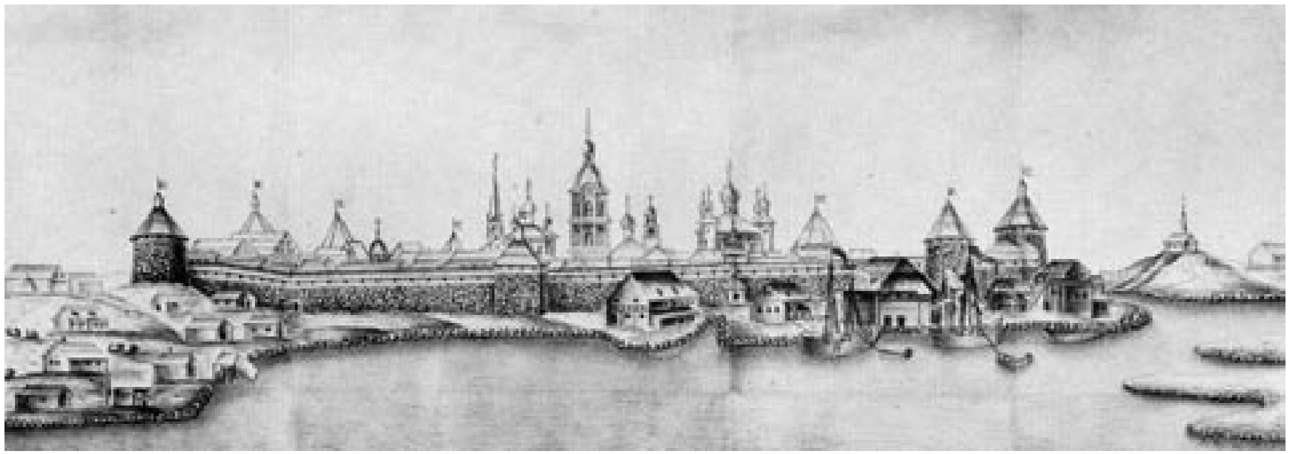
The monastery c1840, with the original dry dock with three slipways.



The monastery in 1887, with the dry dock enlarged to five slipways.

Left: An engraving of the monastery from 1852, with the dry dock to the right. Note the saw mill behind the dry dock. The gates of the dry dock are not shown mitred (meeting at an angle), and the stonework of the entrance is shown tapered, whilst today it is parallel. Either the drawing is incorrect or reconstruction in the 1880s was more comprehensive than has been suggested.

Below: A view of the monastery from c1790. The dry dock was built some years later in the inlet shown on the right hand side.



1 Summary

An historical audit of the dry dock on the Solovki Islands was carried out to assess the historical development and importance of the dry dock in local, regional, national and international terms. Historical document sources and reports in the archive of the Solovki Museum were inspected and the dry dock itself was appraised in detail. The report presents a general introduction to the development of dry docks. The structure of the Solovki dry dock is then considered, and suggestions given as to its historical significance.

In conclusion, a series of recommendations are made as to the possible conservation, operation and interpretation of the dry dock.

Note that the dry dock is formed from two distinct areas, the wet dock which is always full of water, and the 'slipway' area, where boats can stand on keel blocks and which is only covered by water when the dock is filled above the level of the White Sea.

A view of the hydro-electric station around 1920. Note the water outlet into the dock, the fencing and the bridge structure over the outlet. The road level was subsequently raised and the bridge is now in a poor condition.

2 Introduction

2.1 Background

The Solovki archipelago comprises six islands situated in the south-west of the White Sea. In total, their area is approximately 300 square kilometres. They have been inhabited since the 5th Century B.C., and man-made structures can be found dating from as far back as the 3rd Millennium BC. A Russian Orthodox monastery was established on the archipelago in the 15th Century, and several churches built between the 16th and 19th centuries survive. The monks also developed industry on the islands, and many small-scale industrial buildings can be found. Shipping was always an important aspect of life on the islands, and the dry dock was built around 1800 to support these activities. Between the 1920s and the 1990s, the islands were used at various times as a concentration camp and military base. The Solovki Islands were declared a World Heritage Site in 1992. More details can be found in Appendix 1.

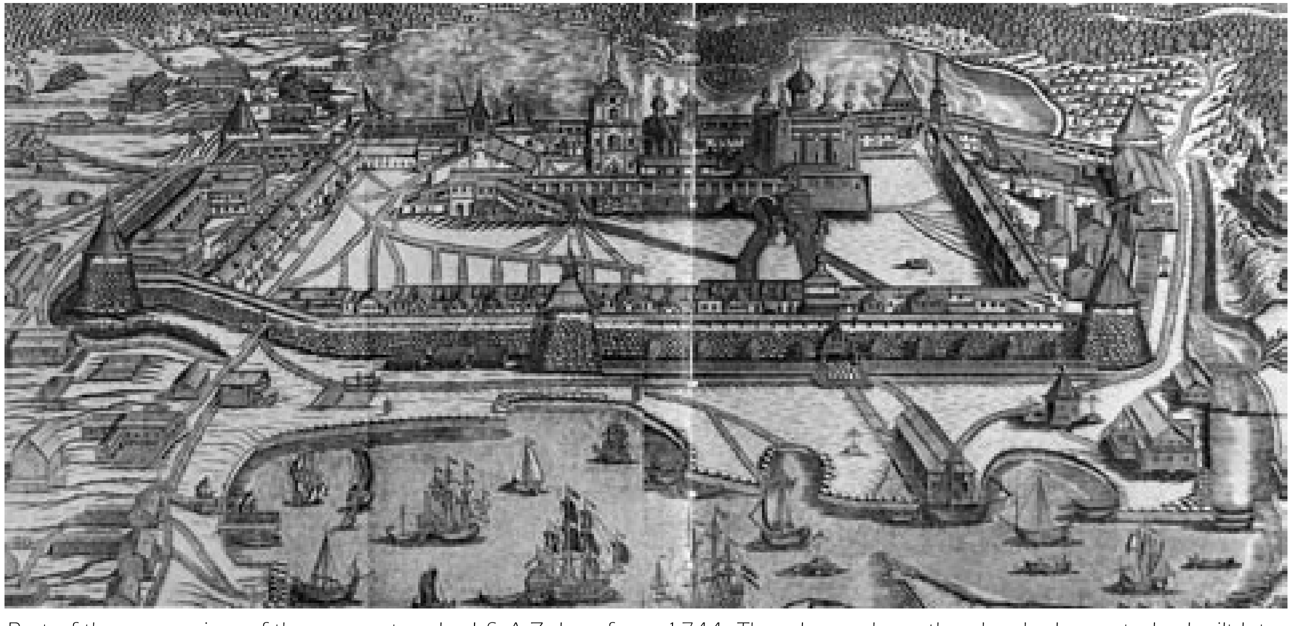
This historical audit looks at the history of dry docks in general, and the Solovki dry dock in particular. The problems of conserving and interpreting it are considered and recommend-ations made for future action. The audit was undertaken by Mike Clarke of Milepost Research in co-operation with Dipl-Ing. H-J Uhlemann, the Solovki Museum, Wroclaw Polytechnic and the Russian Institute for the History of Science and Technology.

2.2 Organisation of Report

The report first provides an overview of the development of dry docks in Europe. Then, after describing the historical sources used in the Solovki Museum, the construction, development and use of the Solovki dry dock is considered. Its history is described chronologically, and its enlargement in relation to the increase in shipping in the mid-nineteenth century is reviewed. Suggestions are given as to how the dry dock was operated. The report closes with a discussion and appraisal of the significance of the dry dock, with recommend-ations for its conservation, operation and interpretation.

As all documents used during research were in Russian, a language of which the author has only a basic knowledge, the report will have some minor inconsistencies. However, discussion with staff of the museum and observation of the system itself will have ensured that the information in the report is useful and comprehensive.

An engraving of the monastery from the 1840s. The dry dock is on the extreme right, but only the wet dock area is shown here.



Part of the engraving of the monastery by I & A Zubov from 1744. The place where the dry dock was to be built later is on the extreme right of the illustration.

3 The Dry Dock

HMS Victory *in dry dock at Portsmouth, showing the stepped dock sides and support props — a typical 18th century naval dock.*

3.1 General introduction

The construction of small boats is a comparatively simple process requiring a small piece of flat ground. The small size of boats allowed them to be manhandled or carried on light wheeled carriages between the boatyard and a launching site next to the sea. However, in the 15th century, the size of naval vessels had increased such that it made moving them over land impossible. Construction sites needed to be alongside the sea, allowing the ships to be launched down slipways, though their great weight could make this difficult. For repair, they were beached at high tide, but this meant that work had to stop during successive high tides.

The dry dock was the answer to these problems. At first, they were little more than hollows excavated on the foreshore, perhaps with wooden sides and with water being kept out by clay banks. The clay had to be removed to allow access to and from the dry dock. Over the years, dry docks developed to become more permanent structures with stone walls and wooden gates. At the end of the 17th century, stone-built dry docks with stepped sides were built for the Royal Navy at Portsmouth and Plymouth by Edward Dummer. When in dry dock, ships had to be kept upright, and the stepped sides made it easier for props to be used.

In use, ships entered the dry dock after which the gates were closed. The ship was then positioned over wooden blocks fitted along the centre line of the dock floor and the water removed either by pumping or by waiting until the tide had receded and allowing it to flow out through sluices. While this was taking place, props were inserted between the ship and the dock wall so that it did not fall over. When the water had drained, the ship was left sitting on the blocks, which allowed the boat repairers access to the keel and made it easier for them to work underneath.

Because of the difficulty and expense in constructing and operating dry docks, 'grids' were often used instead. These were open frameworks, usually of wood supported on wooden piles. Their level was just below the high water mark, so ships could be floated over them. As the tide went out the ship was left sitting on the grid out of the water. They were only used where the tidal rise and fall was large.

3.2 European Dry Dock Development

The first naval dry dock was built during the reign of Henry VII at Portsmouth. It was completed on 25 May 1496. The entrance was formed by two dock gates which overlapped and were sealed by clay filling the space between them. The structural walls of the dock were wooden, and it was emptied by an 'injyn' (engine), presumably some form of pump. Later dry docks were often located where there was a large tidal rise and fall, which allowed the dock to be drained at low water. One problem with constructing a dry dock was the variation in pressure on the walls. When the dock was full of water, this exerted an outward force. The direction was reversed when the dock was drained. Consequently dry docks built with timber or soil walls were always liable to collapse. Some seventeenth century dry docks had gates which had three hinged sections and required up to 70 men for their operation.

Edward Dummer built the first stone dry dock at Portsmouth in the 1690s, and he used mitre gates (two gates meeting at an angle) on its entrance, possibly the first such gates in England. Chain pumps worked by a horse drained the dock, but a water wheel may have been used as well, though only at low tide, water to power the wheel coming from the wet dock. Further dry docks were built at England's naval bases throughout the 18th century. Master shipwrights preferred building new ships in dry docks, but this was considered to be an extravagant use of such an expensive structure, so slipways were normally used instead, and dry docks just used for ship repair. By the end of the 18th century their design had become more scientific, with mitre gates providing a good watertight seal. Proper foundations with inverted arched floors were introduced by Samuel Bentham, Inspector General of Naval Works (he had previously visited Russia), in 1799, greatly increasing the strength of the structure. He also introduced caissons to replace gates, and this allowed for much wider entrances to be built economically.

However, water still required removal and the dry docks at Portsmouth were connected to a deep sump in 1771. Water drained into this sump and was then removed by chain pumps, usually horse powered. A steam reciprocating pump was installed in 1797 which drained the dry dock sump at night and powered woodworking machinery during the day. Subsequently, in the 20th century, electricity was used to power pumps to keep the water out of dry docks.

Dry docks were also a feature of Swedish naval bases, with the well-known naval architect Chapman recommending their use for storing vessels at the Sveaborg dockyard in Finland. By 1780 fourteen vessels were in store there. On northern seas which froze, boats did not go to sea in winter. Besides the usual problems of keeping vessels at sea, the ice could easily crush a wooden vessel or severely damage its hull when under way. It was important that they should be stored and conserved in the best possible condition. So here, dry docks were used not just for repair, but also for storage.

Earlier, a dock yard had been set up at Karlskrona at the end of the 17th century. The first dock yard was on the island of Vämö, but it was moved to the present site on Trossö around 1694. The first dry dock was built by Paul Lejonsparre between 1716 and 1724, and this replaced, to some extent, the careening embankments, built by C Polhem around 1700. Here, ships were rolled virtually onto their sides so that they could be repaired. The well-known five-finger dry dock complex was developed between 1756 and 1852.

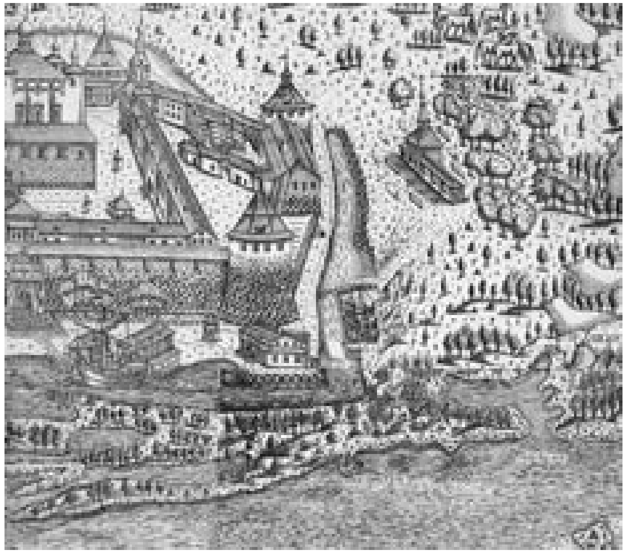
3.3 The Solovki Dry Dock

The engraving by I & A Zubov of 1744 (see page 22) shows the area to the south of the monastery before the dry dock was built. It may have been used as a wharf, an extension of those in front of the monastery, or as a boat building area and for winter storage of boats. Water ran down from the Saint Lake through a trench fortification similar to that which still survives to the north of the monastery.

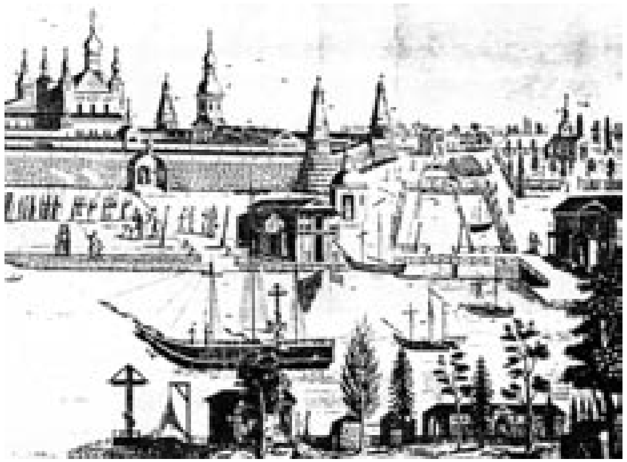
The construction of a dry dock was decided upon at the end of the 18th century. It would be used both for boat building and repair, as well as for storing boats during the winter. It was important for wooden boats, where possible, to be kept out of the water during winter because they could be damaged by ice. The dry dock was built between 1799 and 1801. It was unusual in that it did not use tidal variations to create a difference in water level within the dock, nor was water pumped out of the dock. Instead, the water level in the dry dock was raised by water supplied from the Saint Lake, whose level was some eight metres above that of the White Sea.

The dry dock had a wet dock area which always contained water and a slipway area alongside whose level was just above the White Sea's highest tidal level. The dock operated as follows. First the gates were opened and a boat would sail into a wet dock area. The gates were closed and the dock was filled with water from the Saint Lake. When the water was high enough, the water feed was stopped and the boat was moved sideways over the slipway area where, on the original dock, there were three rows of wooden or stone keel blocks on which boats could sit. The boat was held over a row of blocks and the water drained from the dock. This left the boat standing on the keel blocks, allowing it to be stored or repaired.

Two rows of wooden piles were installed either side of the entrance, with earth and clay being used to fill the space between. A simple entrance gate was probably used, and the sides of the dock were formed from stone and earth, probably sitting on wooden piles. Contemporary drawings do not show any control mechanism for the water supply from Saint Lake used to fill the dock. Perhaps this was on the side of the Saint Lake, though provision would also have been necessary for drainage for the water which powered the water mill within the monastery and which runs into the White Sea close to the dry dock. Three lines of



The same area from an engraving of 1804. Note that there are three ships in the dock, one on each of the lines of keel blocks. After reconstruction in the 1840s, there were five lines of keel blocks.



The dry dock from a drawing of 1865. Note that the dock's slipway area is shown with a wall around its three sides. Today the right hand wall is a grassed area and the furthest three sets of keel blocks were longer. Were they lengthened during the reconstruction in the 1880s or is this drawing incorrect?

keel blocks were erected on the dry dock area, allowing three boats to be stored or repaired at the same time. In use, the dock was found to have insufficient strength, possibly referring to the entrance and gate, and it had to be repaired in 1822.

Nineteen years later, in 1843, reconstruction of the whole structure began, and this was completed in 1846. The entrance was completely rebuilt. The new structure may have been erected inland of the original entrance which could have been used as a dam to protect construction work. Contemporary maps are not accurate enough to confirm this, but evidence of a twin wood piled wall remains just outside the present dock entrance. The new dock comprised a wooden framework around its circumference, and this was infilled with stone and earth. The wall with the entrance gates was lined with dressed granite stonework, while around the other three sides natural random stonework was used. The edge of the wet dock area was lined with dressed coping stones. During reconstruction, the slipway area was extended to give space for five sets of keel blocks. The dock had to be extended to accommodate these, and the new area allowed longer vessels to use the dry dock. This was possibly because of the increased size of boats due to the introduction of steam power.

Further alterations were made in 1880-1 when the mitre gates were replaced, the depth of water in the wet dock increased to 1.2 metres and the total height of the dock walls increased to 6.5 metres. In 1908-13 there was further reconstruction, probably because of the construction of the hydro-electric station next to the dry dock. The gates were also repaired in the 1920s, and other work was undertaken in the 1930s. Since 1947, the dock has not been filled with water for use by large boats, and it remains as a harbour for small boats. During the winter, these are pulled out by hand onto the slipway area for storage.

3.4 Water Supply

The dock lies to the south of the monastery, on the line of the original drainage channel from the Saint Lake to the White Sea. Before the dock was built, there was a bridge across this channel approximately in line with the back wall of the dock. On the seaward side of the bridge was a wharf, and possibly a winter harbour for the storage of boats when not in use.

There are few details of the water supply to the original dock, though a water-powered saw mill was built later between the dock and the Saint Lake. Water from this, and the water mill within the monastery, must have had its own channel into the White Sea avoiding the dry dock. It was probably the one which still survives, though slightly altered. The saw mill remained in use until the construction of the hydro-electric station c1910.

A control basin was probably built as part of the hydro-electric scheme just to the north of the station. Water can enter this from the Saint Lake, from the water mill within the monastery and from the hydro-electric station. There are two exits, either directly into the White Sea or into the dry dock. Both were controlled by simple sluice gates fitted over their entrances. Thus water could either be fed into the White Sea or diverted into the dry dock. Water from the hydro-electric station could also be fed directly into the dry dock. In normal times, this would not be a problem as the dock level would be below that of the hydro-electric station. Water would only need to be diverted when the dock was filled, and this was unlikely to happen on a regular basis.

The Dry Dock from the monastery.

4 METHODOLOGY AND SOURCES

4.1 The range of evidence

This report has been written following a two-week visit to the Solovki Islands at the end of July, 2001. Archive and bibliographic sources within the Solovki Museum were consulted, and the dry dock and its water supply channels inspected.

In the Archive were reports by Russian historians written over the last fifteen years. A detailed survey of the dry dock area been undertaken, and ground plans drawn up, but there were no detailed drawings of the structure or dock gates. There are contemporary documents, but from footnotes in the reports held in the Solovki archive, many of these seem to be in archives in Moscow and St. Petersburg so were not available for inspection. Many sources were also probably destroyed in the 1920s when the monastery was severely damaged by fire.

Because of the lack of technical document-ation, much of this report is the interpretation of site visits based on personal specialist knowledge. The various old maps and photographs available also produced much useful information.

The remains of the water supply control sluice in the basin to the north of the hydro-electric station. The wooden frame is fixed against the dressed stone wall suggesting that it may have been added later.

The other end of the water supply tunnel where it enters the dry dock.

5 Technical Description

5.1 The Dry Dock

On either side and just in front of the entrance to the dry dock are wooden walls parallel to the dock entrance wall. These consist of two sets of wooden piles about one metre apart, the gap being filled with earth and stone. It is possible that these are the remains of the original dock wall, and that they were retained to keep water out of the dry dock area during reconstruction. Only those sections close to the edge of the water have survived. Another possibility is that the remains are part of a temporary dam built during one of the docks subsequent reconstructions.

The entrance wall to the dry dock has been altered several times. The original capping stonework has been raised around 0.5 to 0.7 metres at some stage during rebuilding. It is of dressed granite about 0.25 metres thick, and has a quarter round convex chamfer on its upper outer edge. The other original stonework is from 0.7 metre thick dressed granite, five courses being above water level. An additional course of dressed granite, about 0.5 metres thick, has been added subsequently. The wooden framework across the top of the wall was probably added at the same time as the wall was raised. There may also have been some structural weakness which this was attempting to overcome. The level of the sliding bridge rollers on the coping at the edge of the wall are higher then those further from the edge. The bridge was still in use circa 1910, so some of these alterations may have taken place after this date. (However, the rollers may originally have been at different levels)

The northern entrance wall showing the various alterations and the crack, right, in the structure.

Pairs of wooden mitre gates such as those used on the dry dock would probably have a life of around fifty years, so it is likely that they have been replaced several times, possibly during reconstruction in the 1880s and then in the 1920s/'30s. The present gates are 6.40 metres wide, so that when they were closed they would form an angle of about 90 degrees across the 9 metre wide entrance. Compared to lock and dock gates elsewhere, this is excessive — the usual angle made by a pair of mitre gates being around 150-140 degrees. Either the design of the entrance is unusual or the present gates are second hand and have been made to fit. Underwater, the gates fit against a wooden sill, a triangular wooden structure fitted to the bottom of the entrance, to make a watertight seal. Investigation of its design and condition would help in understanding the history of the dock entrance. With mitre gates at an angle of 150 degrees, most of the forces created, when the gate is holding back the water in a full dock, are directed along the line of the wall. However, with an angle of 90 degrees about half of the forces are directed at right angles to the wall (parallel to the entrance channel), and this could create problems with the stability of the wall.

The gate quoin, where the end of the gate fits into the wall, is unusual. In stone work, these are usually curved recesses, and the end of the gate is rounded to sit and move against them (see picture on page12). The two curved surfaces fit together smoothly to form a watertight seal when they are pressed together by water pressure. The quoins on the dry dock are formed by flat dressed surfaces, and are trapezoidal in cross-section. The rounded end of the gates fits into these recesses, and it is probable that the seal was prone to leakage. This problem would be compounded by the gate straps — the ironwork which holds the top of the gate and forms the upper bearing. These should be adjustable to allow the position of the gate to be moved so that a good seal is formed. Here they are solid, and they are also hidden under a shaped coping stone. Any alteration to make a good seal would be difficult.

There are a number of pieces of ironwork fitted to the wall of the entrance channel, but their use is uncertain. The recesses in the stone work are mostly for some form of strengthening for the gates. Possibly the earlier gates were at too shallow an angle and were in danger of being pushed outwards by the weight of water in the dock when full. Wooden struts could have been inserted into the recesses to support the gate. There is also a vertical recess travelling downwards from about one metre above water level. This was probably used for stop planks — heavy wooden beams whose ends fit into both slots and which sit one on top of another — and these are used to keep water out during repair. Underwater they sit on a wooden beam fitted across the bed of the entrance channel so that they make a watertight seal.

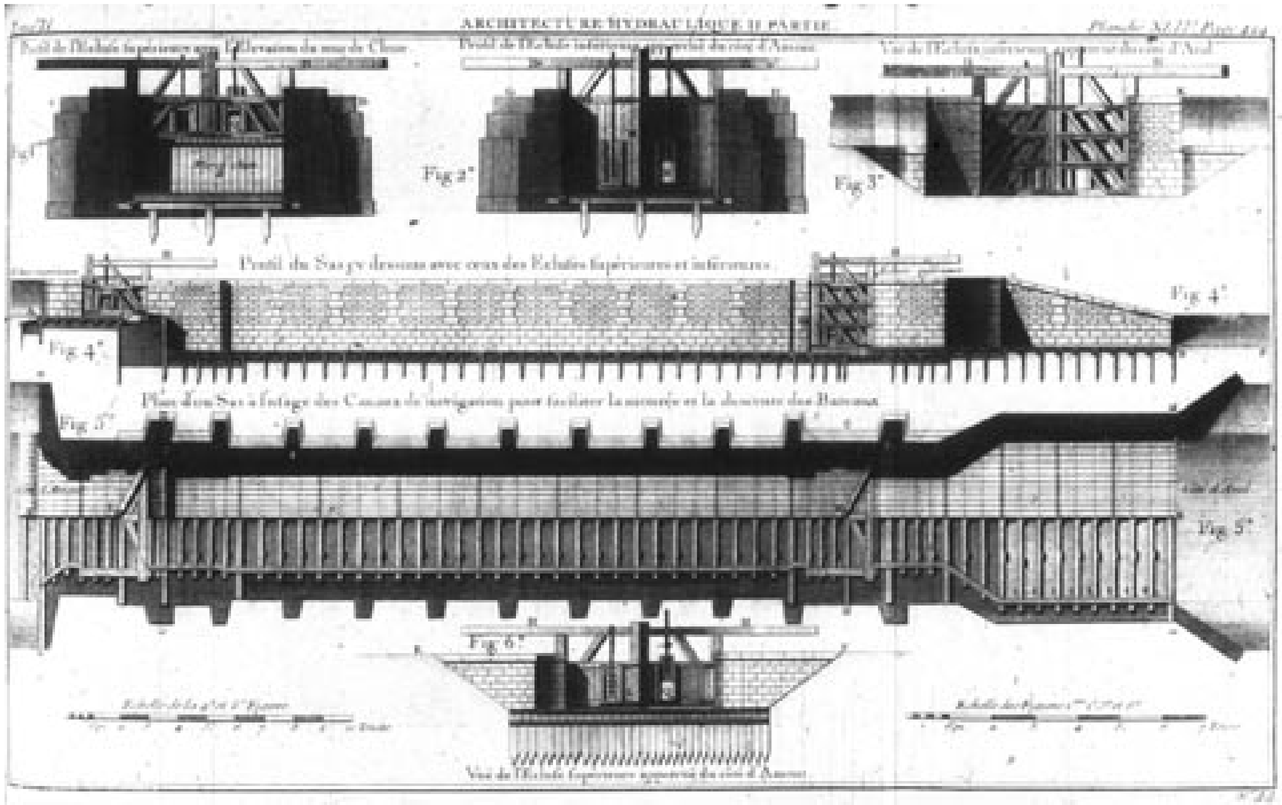
A photograph of a wooden gate sill on an English canal lock. Details vary from canal to canal, as does the angle of the mitre. However, they are usually around 140 degrees. The gates on the dry dock should have a sill similar to this to form a watertight seal.

The wet dock is fairly conventional, with dressed coping stones around the edge. In places on the dry side, these have been removed or moved to make it easier to launch and retrieve the small boats which now use the dock.

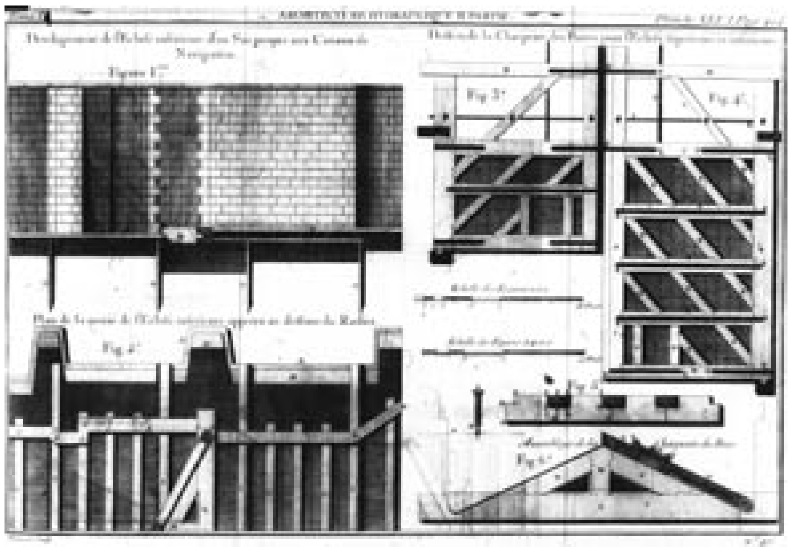
The original dry dock had 'slipways' for 3 boats of around 25 metres length alongside each other. One of these may have been built on by the new dock wall during reconstruction of the dock in the 1840s. Three more slipways were added at this time on the inner side of the dock to increase its capacity, and these were almost twice as long as the earlier ones. Each slipway would be formed from a series of wooden blocks fixed so that their upper surfaces were level, or possibly angled slightly towards the wet dock. Ships could then sit on top of these safely whilst repair work took place. Blocks such as this were usually removable (one at a time) to allow full access to the bottom of the ship. The remains of some of the blocks can still be seen around the slipway area.

The dock walls are formed by a random stone facing to earth banks. Only the walls close to the entrance gate are from dressed stone. The floor of the dry dock area also appears simply to be earth. It is unlikely that any of the earth works will be lined with clay to make them water tight, and water would be draining away continuously when the dock was filled. As mentioned above, the gates were also likely to leak where they were fitted to the walls. Such leakage was probably not too dangerous to the structure of the dock because it would only have been filled for short periods of perhaps two or three hours. As the level was only just above that of the sea, and consequently the local water table, water pressure differences could probably be contained by the simple dock construction. There was also plenty of water in the Saint Lake to replace any leakage. The entrance walls would present the greatest danger with regard to water leakage, and this is probably one of the main reasons for their construction with dressed stone.

The fencing around the dock varies considerably over time, and the present fencing probably dates from the 1950s or '60s. several photographs show the dock without fencing, or with it just along the roadways. The



Two pages from Belidor's 'Architechture Hydraulique', the standard French work on hydraulic engineering from the early 18th century. They show the wooden sill against which the gates sit, and the angle of the gate mitre.



Above and right: Photographs comparing the quoin on the Solovki dock gates (right) with those found on English canals (above). The Solovki quoin has plain flat surfaces, whilst the canal quoin is curved to form a hinge for the gate. Note the cast iron bearing for the gate on the lock floor. These could either have a hole, as this one, or could be a pin fitting into a hole in the bottom of the gate.

Left: Two views showing the raised coping over the gate quoin on the side of the dock entrance, together with the bridge rollers. Note the quarter-round chamfer on the edge of the coping stones.

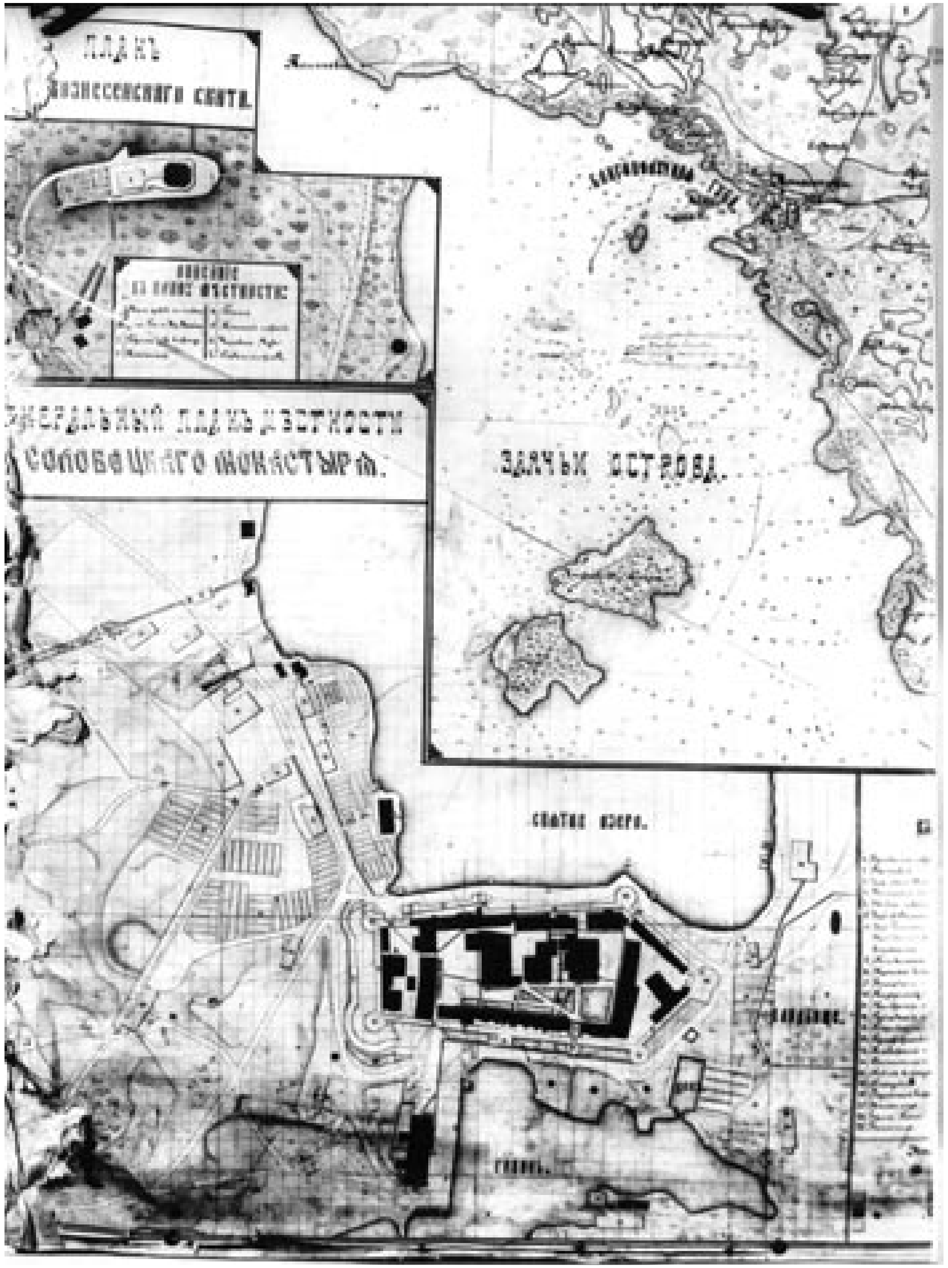
most typical appears to have had a wooden top and bottom rail with smaller X-diagonal struts between the uprights. The level of the roadway between the dock and the hydro-electric station has been raised over the years. It has also been widened, and is now dangerously close to the edge of the dock. A particular problem section is the bridge over the water outlet into the dock from the hydro-electric station. The wooden supports here were probably considered a temporary structure when installed and are now unsafe.

5.2 Water supply

Water is supplied from the Saint Lake, and is controlled by sluices fitted to an open chamber to the north of the hydro-electric station. The underground channels are stone lined and have been well maintained over the years. Some sections, such as that which directs water into the White Sea instead of into the dry dock, have been rebuilt during the twentieth century. The control sluices are of simple construction, with simple windlasses and chains used for raising them. They would not need forcing downwards as they would only be closed when water had drained away and there was no pressure on them.

Nearer to the Saint Lake, it is possible to see parts of the original water supply channels, but there has probably been some alteration to the system during the construction of the hydro-electric station.

The water from the supply tunnel entering the dock and, right, inside the water supply tunnel.



The site in 1908 before the hydro-electricity station was built.

Two photographs of an English canal dry dock of similar construction to the Solovki dry dock. Note the stop planks for keeping the water out, and the keel blocks on which the boat sits. Water is allowed to drain away into the canal below the two locks on the right of the bottom picture. This dry dock suffers from leakage through its walls when full, resulting in water entering the cellars of the houses. Dock walls of this type are always difficult to keep watertight.

6 Discussion and Appraisal

The Solovki dry dock is an ingenious solution to a practical problem. A dry dock was required for boat repair, boat building and winter storage, but such structures were expensive to build and maintain. Perhaps the greatest operational problem was keeping the dock dry and free of water. In conventional dry docks this was achieved by pumping, which was time consuming and expensive. By supplying water to fill the dock from a lake above sea level, and then forming the dock yard area above normal sea level, no pumping of water was required.

There are few similar examples elsewhere of this type of solution. Dry docks associated with canals often provided similar solutions, though without the need for a wet dock area. Canals were usually above the water table, so after canal water had been used to fill a dry dock it could then be led away into natural drainage channels. Dry docks built on the coast did not have this possibility as they were constructed at the level of the water table. Also on canals, there are a couple of examples of locks where the upper part of the chamber was widened. This was usually done to increase the supply of water flowing down a flight of locks, but it could also form a temporary area for repair work on boats.

Some work will be necessary to return the dry dock to a usable condition. Structurally, the most difficult area would be the sea wall and entrance. This has been altered several times with additional wooden frames for strengthening. Much of this wood has decayed and it now provides little extra support for the original stone structure. The upper course of stone, which has been raised, is unstable, and there are some signs of movement in the main sections of the dressed stone wall. This is particularly noticeable on the sides of the entrance, where cracks in the wall suggest that the structure has been pushed outwards towards the sea. This could be a result of the wide gates which seem to have been installed in the 1920s/'30s. When the dock was full, the forces on the gates would have resulted in a greater shear force on the dock wall than with narrower gates. With the latter, there would have been a greater compressive force acting along the line of the wall which would have been less likely to cause a fault in the structure.

The side walls of the dry dock may require some stabilisation, particularly around the two water supply channels and where the roadway runs between the dock and the hydro-electric station. However, as the dock is below ground level and has survived for two centuries, it is unlikely that major works will be required. The only exception is the roadway where it crosses the water channel from the hydro-electric station. Excessive traffic here may have caused some structural problems, but these could be overcome, to some extent, by diverting heavy traffic away from this section of road.

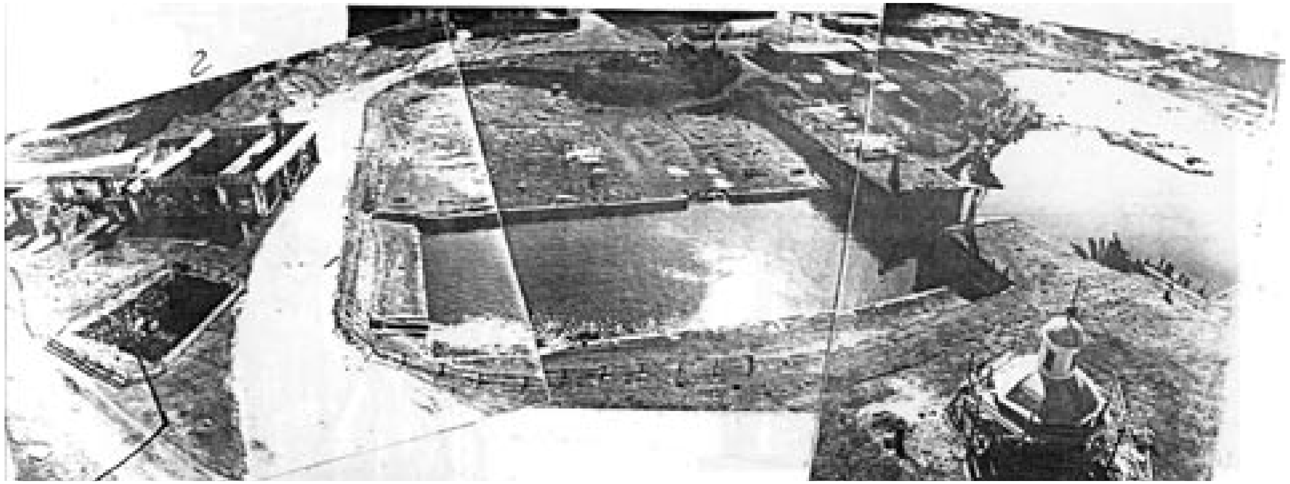
The slipway area has become covered with grass, though remains of the wooden blocks used to support the ships here can still be found. There may be a more solid and well drained surface underneath the grass as a dry level surface is better for working on boats. However, in the nineteenth and early twentieth century, these were not always considered a high priority, and contemporary photographs show wooden planking forming walkways alongside the slipways.

The sluice gates fitted to the basin to the north of the hydro-electric station are of a very simple type and would not be difficult to rebuild. The one controlling water flowing into the dry dock is fitted flush to a flat dressed stone wall, while the one controlling access directly into the White Sea is in a rebate in the dressed stone. Could the two sluices date from different periods? Alterations would certainly have been required when the hydro-electric station was built.

The dry dock is a further example of the way the monastery used the natural geography of the islands to their advantage. The small tidal range of the White Sea and the rocky coastline would have made it difficult to haul boats out of the water for repair and for the winter. By creating the dry dock, the monks were able to take advantage of the increasing size of boats available in the nineteenth century. It would also have allowed the introduction of steam power, which resulted in larger boats. The development of the monastery relied upon good communications with the mainland and with the outlying communities associated with the monastery. The dry dock allowed the monastery to take advantage of new developments in boat design which, in turn, provided the more reliable communications vital to its development.

A view of the dry dock from the monastery, taken around 1910. Note the type of wooden fencing around the dry dock and supply basin, and the bridge over the dock entrance.

The Solovki dry dock during use by the Russian Navy c1950.



A composite photograph of the site from the Solovki Museum archives.

7 Recommendations

7.1 Re-use

The approach to conservation of the dry dock will depend upon how it will be used in the future. There are two main possibilities:

1. Conserving it in its current condition and continuing its use as a harbour and storage area for local and visiting small boats.
2. Returning it to a condition where it would be possible to use it as a dry dock.

The problem with the first option is the severe winter weather. The structure of the sea wall is already beginning to fail, so that major work will eventually be needed just to conserve it. Some archaeological excavation work will also be needed to determine the history of the entrance area and the slipways. This would probably require the removal of much of the earth covering which has built up over the years.

The second option would be expensive as it would require the construction of new gates, the renovation of the underwater sill against which the bottom of the gate sits when the gates are closed, restoration of the slipways, renovation of the water feed system, and renovation of the sea wall. However, it is probably the best solution. However, given the existence of some structural movement in the sea wall, restoration to maximum depth of water in the dock is not advised. At one time vessels up to 50 metres in length and drawing around one and a half metres could have used the slipways. It is suggested that the size of vessels capable of using the restored dry dock is reduced such that the dock does not need to be filled completely. This will reduce the outward pressure exerted on the sea wall.

Work could be carried out in stages, with the dock continuing its present use until restoration was complete. Even then, it could be used by local people for the storage and repair of their boats. Special days could be set aside for the operation of the dry dock, perhaps in spring and autumn, when boats could be put into and removed from winter storage. The slipways could also be used for wooden boat construction, preserving local boat building methods, providing training and work for local people, and producing small wooden boats for sale. Such a product could be used to advertise the islands and museum at boating events outside of Russia. This usage would require co-operation with the development of the other boatyard and slipway.

The recommendation would be for restoration to the dry dock's original condition in stages. These could be undertaken as money becomes available, the stages being as set out below.

7.2 Conservation

The dry dock should be drained so that the sill at the bottom of the entrance can be inspected. The gates and sill will be expensive to restore, so it is important that full details of what work is necessary are obtained fairly early in the programme. While the dock is drained it should be cleaned and the walls inspected. It may be possible to undertake restoration of the basin edging at this stage.

The sea wall will require considerable work in restoring the various wooden frames which have been installed, and making the upper stonework secure. The type of surface for the top of the sea wall will need considering, as this could help to keep the wall weather proof and reduce winter damage. Features such as the bridge rollers will also need conservation. When the sea wall has been restored it would then be possible to install the entrance sill and gates.

The slipway area will require an archaeological survey, including the removal of the grass surface to be able to locate the positions of the timber baulks for supporting boats. The final use of this area needs to be decided before this work is undertaken, so that a suitable floor can be reinstated afterwards. It would be possible to fit one set of baulks to show how the dry dock was used, the rest of the area being left level for use by small local boats. The dry dock would also make a suitable site for events, such as concerts, during the summer.

The final stage would be the restoration of the water control system, though as this would not require much work, it could be undertaken at any time.

The edge of the dock will need to be fenced, the existing steel and chain fence being replaced with one of a more traditional design. The roadway between the hydro-electric station and the dock needs much urgent work to prevent an accident. As mentioned above, heavy road traffic is damaging the structure of the hydro-electric station and the extension which widens the roadway at this point has become structurally unsound.

The dangerous section of road by the hydro-electric station outlet.

7.3 Documentary Evidence

There are several reports on the history of the dry dock in the museum archives, but only a general survey has been made of the site. Further recording is needed, particularly of the entrance gates, sea wall and slipway areas. This would enable a more complete history of the dry dock to be drawn up, particularly of the bridge over the entrance channel, the dock gate system and the way the slipway area was used. Such information will be required for a full interpretation of the site.

The Solovki dry dock is the only one known to the author where water is supplied from inland sources to a maritime dry dock. However, further research needs to be undertaken into dry docks in Scandinavia built in the eighteenth and nineteenth centuries. The small tidal variation and mountainous terrain around the Baltic would make such a solution for the construction of a dry dock advantageous.

7.4 Interpretation

The interpretation of the dry dock will depend, to some extent, on how it will be conserved. If it is not returned to operational condition, signage should be erected at three sites:

1. The entrance gates explaining the dock's operation. Details of the bridge across the entrance could also be included here, as well as a transcription of the inscriptions on the memorials on either side of the entrance.

2. Near the slipway area to show how it was used. The increasing size of boats could also be included as well as some details of boat building. (This may have to complement the work being done on the boat yard further around the water front)

3. By the water supply basin to indicate the various underground channels, the control sluices, and how the hydro-electric station has affected the water supply.

If the dock is returned to operational condition, an annual programme should be drawn up for its use. The exact details will depend upon how the dry dock area is used. Two possibilities are for it to continue as a harbour for small visiting and local boats, or as a boat building and repair site providing training and work for the local community. Both of these uses will restrict the number of times the dry dock could be filled with water. Its use as a winter harbour would mean that it would be used twice a year, in spring and autumn, and these could be made into special occasions. It may be possible to arrange for a 'Blessing of the Boats' ceremony to be carried out by the monastery, as this is something which happens at many places around Europe, and could be publicised to attract tourists.

7.5 Publications

The results of research into the dock's history and the comparison of this with other dry docks in northern Europe should be published in the academic press. This could complement any research into the trade links which existed in the region, and the development of shipping and ships, particularly with Scandinavian countries and Britain. Details of the operation and use of the dry dock should be included in a guide to the Solovki Islands, though a leaflet just about the dry dock would probably have limited appeal.

Appendicies

1. Approximate date for structures on the canal system.

Canal K5 viewed from Sluice 1 looking to the south. The water level appears to have been raised and covers the bank protection.

K1	16th Century
K2	16th Century
K3	16th Century
K4	19/20th Century, it replaced K32)
K5	16th Century, rebuilt 19th Century
K6	16th Century?
K7	20th Century?
K8	16th Century?
K9	20th Century
K10	20th Century
K11	20th Century
K12	20th Century
K13	20th Century
K14	19th Century?
K15	19th Century
K16	19th Century
K17	19th Century
K18	19th Century
K19	19th Century
K20	19th Century
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K35	18th Century
K36	18th Century
K37	18th Century
K38	18th Century
K39	19th Century
K40	19th Century
K41	19th Century
K42	18th Century
K43	18th Century
K44	18th Century
K45	20th Century
K46	20th Century
K47	20th Century
K48	20th Century
K49	20th Century
K50	16th Century

Dams

D1	20th Century
D2	20th Century
D3	20th Century
D4	16th-18th Century
D5	20th Century
D6	19th Century

Weirs

P1	20th Century
P2	16th Century
P3	18th, Raised 20th Century?
P4	18th Century
P5	Raised 20th Century
P6	20th Century

Sluices

S1	20th Century
S2	16th Century

2. From World Heritage Review 12

The Solovetsky archipelago: evaluation and prospects

The Solovetsky islands in the north of Russia (65° latitude N, 35° longitude E), embrace about 300 square kilometres of land raised above the White Sea after the thawing of the last glaciers. They are marked with glacial hills, ridges and depressions covered with thick taiga forest, countless blue-eyed lakes, broad moss bogs and vast expanses of seaside tundra with wonderful bird colonies and luxuriant northern berry-fields. The islands are strewn like a lost necklace on the wide steps of the terraced sea. Filled with the memory of their geological past, they preserve numerous gigantic sea ramparts, stone "rivers" (stone-lined canals), and sand dunes. Clusters of smaller islets attract maritime creatures and birds. On this territory too, more than four millennia ago, humans were already performing their ritual activities.

The first inhabitants left numerous material traces, including so-called "labyrinths", stone mounds, and various other configurations of stone. A large number of such sites are scattered all over the archipelago, especially on Anzer and Big Zayatsky (Hare) islands. Their origins are still uncertain.

The first millennium of the Christian era left hardly a trace on the Solovetsky islands, but in the fifteenth century, the first hermit monks (later canonised) came here to found the Solovetsky monastery. In those days the islands were used for fishing by the neighbouring population but the archipelago gradually passed into the hands of the monastery. Over the next five centuries the monks cleared new lands on the islands and created some remarkable architectural ensembles which, together with the archaeological monuments of earlier millennia, form the present World Heritage Site. All these monuments and sites led to the inscription of the "Cultural and Historic Ensemble of the Solovetsky Islands" on the World Heritage List in 1992, as "an outstanding example of building or architectural or technological ensemble or landscape which illustrates significant stages in human history".

But the cultural and historical aspects are far from the only feature of exceptional universal value on these islands.

The Monastery

Blending the grandeur of a religious shrine and the austerity of a northern fortress, the historical and architectural ensemble of the monastery's central complex dominating Blagopoluchiya (Prosperity) harbour on Big Solovetsky island is the first monument the visitor discovers. Inside and around the fortresses a monastic settlement was created with its own specific way of life and economy. All activities were interrupted during a period of destruction of objects of worship in the 1920s. At that time a great number of crosses marking approaches to the monastery from the sea and connecting it visually to the surrounding area were also torn down.

The Solovetsky monastery was in its day one of the main cultural and spiritual centres of Russia and an important centre of the Orthodox faith. Its cultural influence was considerable and thousands of pilgrims came to it every year from all over Russia and from many other countries too. The monastery played a significant role in the translation into Russian of the Orthodox spiritual tradition, but at the same time it was the first centre in the Russian north to introduce a number of technical achievements and was consequently a centre of innovation.

On Big Zayatsky island, for instance, the first Russian stone harbour was built; while on Big Solovetsky island one of the first dry docks and one of the first power stations in Russia were constructed outside the monastery walls. Remarkable hydraulic engineering systems were created on three large islands of the archipelago. A botanical garden in which plants from warmer climates were grown in hothouses was established there and still exists today. Measures for land improvement were developed. The surrounding landscape of Solovki, as the Russians call the archipelago, still bears numerous traces of these activities.

Roads and waterways lead from the central monastery complex to all points of the archipelago. They connect the monastery with distant sketes (subsidiary monasteries) and hermitages, with holy places as well as with homesteads, fishing bases and other sites. Taken together, they once gave visible form to a vast and indivisible Solovetsky monastery extending over an area of 300 square kilometres. This indivisible complex subsists to this day and is now appreciated as a cultural landscape. Many channels connect hundreds of lakes and lead from the fringe to the centre and to various sub-centres formed by sketes and economic complexes. These channels allowed the monastery commune to use the water resources of the islands for mechanical and, later, for electric power. But they did not only contribute to hydraulic engineering development; the land on Solovetsky was extremely swampy. Undrained lakes were subject to eutrophication (a process in which the lake, rich in plant nutrient minerals and organisms, gets deficient in oxygen in midsummer). The construction of channels, dams, floodgates and land-improving systems consequently changed the insular landscape, dried out considerable areas, and opened up some spacious meadow lands. The transformations even touched the sea. One of the bays, known as the "Philip nurse-pond", was turned into a gigantic aquarium for fish-breeding. A one-kilometre sea dam was erected to establish communication between two large islands.

The Site's Aura

The cultural and historical ensemble inscribed on the World Heritage List is thus an integral part of the remarkable Solovetsky landscape. While the landscape preserves its natural value and beauty, it has been adapted to human use. Buildings interact with the landscape, emphasising its form and proportions. Sound symbols, such as the ringing of bells, are equally important to the interpretation of the landscape as are the various sacred symbols filling the visual space. Surrounding meadows, vegetable gardens, roads and parks take advantage of the landscape's features which the inhabitants adapted by building terraced slopes, retaining walls and drainage systems. As the result of

flow redistribution, the level and configuration of the lakes were changed. Today, they are not purely natural formations. Interlake channels, especially those used for transportation, are an important scenic and functional aspect of the Solovetsky landscape. Here, the "material" field of the landscape interacts with its "mental" field. The latter is also expressed in the island's toponymy which preserves the names of many monks, hermits and legends, and of Christian holy places (Mount Calvary, Favor Mountain, Cape Eden).

The archaeological vestiges of the two millennia preceding our era also constitute an integral part of the Solovetsky landscape. Their configuration is commanded by this landscape from which the builders took their materials. Only the geometry of their lines, their rhythm and combination, their position within the landscape allow the eye to distinguish them from the background. Here and there, close to ancient sanctuaries or on their periphery, Orthodox crosses persist today and intensify the aura of the site. On one of the islands, a skete was built beside a shrine of the former age. Here, the new culture did not destroy the former one but marked its place in the environment. The monuments of past millennia on the Solovetsky islands constitute a remarkable collection of artefacts left by some of the vanished cultures of northern Europe. For density and variety of monuments, the Solovetsky islands are unmatched in any other region of the north. Hence too, their obvious scientific value.

A Tragic Century

The tragic events of the twentieth century left an important historical layer in the landscape of the Solovetsky islands. The monastery having been abolished, a labour settlement and later a concentration camp were installed here where many famous Russian intellectuals were imprisoned. During World War II, a navy training group was quartered on the islands. The wars and dictatorial regimes which marked the twentieth century had a profound impact on Solovki too. The island landscapes preserve the memory of these tragedies and stand as a warning to future generations.

In the early 1990s, the monastery as a religious organisation was re-established on Big Solovetsky island though it did not regain its former functions and influence. The landscape of Solovki retains some remarkably full and varied testimony relative to the traditional monastic culture of Russia before the twentieth century and its influence on the country's development. The islands also fall into the geographical area of the culture of coast-dwellers (the Russian inhabitants of the White Sea coast), one of the few traditional cultures still surviving in the north - though it is threatened today. This culture had a profound impact on the development of fishery and handicrafts that were important branches of the islands' economy.

The Natural Context

The natural context is also of considerable interest. Biologists and geographers are working on the islands all year round. The biological resources of the White Sea have been studied ever since the biological station attached to the monastery was first set up in 1882. Today, a new biological station attached to Moscow State University pursues the investigation of the islands' ecosystems. Indeed, in the opinion of many scientists, the Solovetsky islands should be included into the World Heritage as a "mixed property", and it is precisely as such that they were originally presented. Unfortunately, only their status as a cultural heritage was acknowledged. In all fairness however, it should be mentioned that the documentation presented in the nomination process in 1991 did not adequately reflect the site's natural values: neither the variety of geomorphological structures illustrating the Quarternary Age, nor the wealth of avifauna; nor the presence of important sites of a large variety of European bird species, nor the location of the main reproductive area of white whales near the coasts, etc.

In 1998, at the request of Ministry of Culture of Russia and with the organisation and financial support of the Norwegian Directorate for Cultural Heritage (Riksantikvaren), an international group of experts headed by Professor Herbert Stovel of the University of Montreal, former Secretary-General of ICOMOS, visited the Solovetsky islands. The experts all agreed that Solovki is a remarkable cultural landscape. In the words of Kjersti Scanche, an expert from Norway, "if anything deserves to be called a cultural landscape, it is surely Solovk".

But at the same time, Solovki's cultural heritage was found to be in a critical condition. The experts noted the continuing destruction of architectural ensembles, historical and economic complexes; loss of archaeological monuments due to coastal abrasion; eutrophication of channels connecting natural lakes; destruction of dams and floodgates; secondary swamping of lands and afforestation of meadows. Today two former sketes are threatened with complete destruction, and one small monastery could easily lose its authenticity. In the past, the land belonged entirely to the monastery; but now, along with the monastic commune, many other organisations pursue their activities on Solovki. These include various municipal bodies, a forestry agency, a museum-reserve, an algae plant, a power station and several small private enterprises engaged in a variety of activities including restoration work, hotel business and tourism. Their activities are not co-ordinated. They belong to various administrations and pursue different purposes that are often quite remote from the notion of heritage protection. The authorities of the Solovetsky museum-reserve are not in a position to cope with a situation which has long gone uncontrolled.

A Much Threatened Site

As a result of this, the islands are threatened, not by a tsunami, nor by earthquake, nor even by local wars, but by an inability to organise territorial management as a whole and to define priorities. An inadequate legislative base, a lack of realistic programmes and the absence of any plan to ensure the conservation and development of the landscape of the Solovetsky islands as an object of heritage are some of the obvious problems. Because of this, as recommended by the mission experts, the Solovetsky islands have every reason to be inscribed on the "List of World Heritage in Danger".

Particular emphasis should be placed on the problems of the Solovki settlement now located on the site of the former monastic village. For historical reasons, the present island population is mainly composed of newcomers. Most of them are quite unaware of past cultural traditions and of the universal value of Solovki heritage. This means that the inhabitants need to be informed and educated, and that favourable conditions should be created leading to their involvement in the preservation of the natural and cultural heritage of Solovki and in its vital activities.

Solovki is a complex formation where natural and cultural values interact. It is precisely in this interaction that the universal value of its heritage resides, reflected in the conception of cultural landscapes. Urgent measures should be taken to prevent further degradation of this valuable site.

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3. Mike Clarke

Mike Clarke became a qualified engineer after serving his time as an apprentice fitter with Pilkington's Glass in St.Helens. He has always been interested in the history of transport and for many years used vintage cars for his everyday transport. In his youth, he also worked on several preserved railways. He currently lives in Accrington, Lancashire, UK.

From 1971 until 1987 his full time employment was the restoration of historical industrial structures, such as water wheels, wooden boats, bridges, steam engines, flour milling machinery and textile machinery. He has worked in both the public and private sectors and has been the Engineer for the Leeds Industrial Museum and for the Lancashire Textile Museum, besides acting as Site Engineer for Dorothea Restoration Engineers. For five years he lived on and restored a wooden Leeds and Liverpool Canal barge.

In 1988 he retired because of ill-health, and subsequently worked for three years in the local history department at Accrington Library. During this time he wrote the definitive history of the Leeds & Liverpool Canal. The book was short-listed for the Portico Prize, given to the best book on a subject relating to North-West England.

In May 1991, as a result of the success of his book, he set up his own business, Milepost Research, to research and produce books on industrial history. He also offers a service to industry, museums, local authorities and the media. Amongst work undertaken since then are:

- Articles on the history of European inland waterways for Encyclopedia Britannica.
- Written reports on listed structures for British Waterways, Hull City Council and Associated British Ports.
- Television programmes about the Leeds & Liverpool Canal for the BBC and for Bayerisches Rundfunk.
- Researched and produced canal related display material for museums in Gloucester, Blackburn, Pendle and Goole. The exhibition at Goole won the award for Social and Industrial Museum of the Year in 1996.
- Research, photography and typography for National Museums and Galleries on Merseyside.
- Archive work for British Waterways, North-East and North-West Regions. Research into various aspects of waterway history for British Waterways nationally.
- Articles on the transfer of technology from Britain to Prussia in the eighteenth and nineteenth century.
- Written a biography of Thomas Steers, Liverpool's first Dock Engineer.
- Researched and written a booklet about the history of electrical generation in North-East Lancashire at Padiham Power Station for National Power PLC.
- Written several books on the history of canals in the north of England.
- Lectured widely on waterway and industrial history, including at the TICCIH Conference at the Science Museum in 2000 and at the 1996 Baltic Conference on the History of Science in Riga.

He has travelled widely across Europe, researching a book on the history of European waterways, and developing links with other industrial historians.

Mike Clarke is a member of several industrial and transport history societies in both Britain and Europe. He is on the Publications Committee of the Railway & Canal Historical Society and is the Chairman of a Trust which has been set up to interpret the last remaining hydraulically powered 'Compartment Boat Hoist' at Goole, and is a founder member and President of the Leeds & Liverpool Canal Society. For recreation, he sings in a local choir.